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CLOUDS


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CLOUDS

A DESCRIPTIVE ILLUSTRATED GUIDE-BOOK TO THE OBSERVATION AND CLASSIFICATION OF CLOUDS

BY

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WITH A PREFACE BY

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INTRODUCTORY NOTE.

THIS explanatory guide-book to cloud observation has been prepared chiefly for those who are engaged in the teaching of meteorology and of nature study, and also for that numerous body of people to whose intelligent interest in meteorology our country has always been so deeply indebted. The book has therefore been written as simply and as systematically as possible, the subject-matter being grouped under different chapter-headings in order that any particular branch of cloud-study may be referred to immediately, and it is hoped that any slight unavoidable overlap thereby caused may be pardoned. Footnotes are added in all cases to render reference to original papers easy.

For the professional meteorologist, the cloud-photographs themselves will doubtless hold the chief interest. They represent a selection made from several hundred pictures taken at Aberdeen by methods which were varied so as to give the best possible representation of each particular type.

I have to express my deep indebtedness to Sir Napier Shaw, LL.D., Sc.D., F.R.S., Director of the Meteorological Office, for writing a preface to the book,

and to the Meteorological Office for permission to incorporate the results of investigations made at Aberdeen Observatory upon the clouds. To Captain C. K. M. Douglas, late of the R.A.F., I am greatly obliged for permission to reproduce a number of his wonderful photographs of the clouds as seen from above, taken from his aeroplane, and to him and also to Captain A. E. M. Geddes, O.B.E., D.Sc., late of the Meteorological Section, R.E., I have to express my thanks for services rendered in reading the proofs, and for giving valuable assistance.

GEO. AUBOURNE CLARKE.

THE UNIVERSITY OBSERVATORY,
KING'S COLLEGE,
ABERDEEN, *December*, 1919.

PREFACE.

By Sir NAPIER SHAW, LL.D., Sc.D., F.R.S.

It is with much pleasure that I write some words of introduction to this little book on Clouds, and for many good reasons.

Since 1903 the author of it has been the "observer" for the Meteorological Office at King's College, Aberdeen, where there is a meteorological observatory in charge of a much-esteemed friend, Professor Niven. It is one of seven established fifty years ago by the Meteorological Committee of the Royal Society, then newly appointed, for the purpose of obtaining continuous records of the meteorological elements and auxiliary eye-observations in order to provide material for the scientific study of the sequence of weather represented in outline by the daily synoptic charts compiled in the Meteorological Office from telegraphic reports which were initiated by FitzRoy in 1860. The new observatories were modelled on the one developed at King George III.'s Observatory at Richmond after it had passed into the hands of the British Association for the Advancement of Science in 1842. The other observatories of the same type were at Glasgow, Stonyhurst, Falmouth, Armagh, and Valencia. All of them, except that at Valencia, which has retained its name though it

was removed to the mainland at Cahirciveen, were placed in charge of some independent scientific authority, and for the one at Aberdeen the Professor of Natural Philosophy at King's College was entrusted with the administration of the sum of money set aside for its maintenance.

The seven observatories formed the group of "first order stations" of the British meteorological network when the collection of observations was systematised by international agreement in 1874, and the chief of their duties was to supply a series of hourly values of the meteorological elements by which the data from the climatological stations could be controlled.

As time went on these duties became a regular routine: the records of pressure and temperature and humidity were photographic, and what they had to tell concerning the weather could only be known at intervals of two days when the sheets were developed; the other records of wind, rain, and sunshine were daily. Hence it came to pass that the "observer" had scanty opportunity for tracing the connection between any unusual occurrence in the way of cloud or wind or rain and the changes in the other elements with which it was associated. Only two of the seven, Aberdeen and Valencia, contributed observations to the Daily Weather Report, and so it came about that the certainty of getting in due time good records of all the important meteorological elements enabled the "observers" to lead a regular and comparatively uneventful life tending instruments and observing at fixed hours. The study of weather as a personal enterprise degenerated into the

manipulation of the tabulations of records at a central office.

But at Aberdeen Mr. Clarke has brought an official nephoscope and his own camera to aid a very keen eyesight for things to be seen in the sky and a most valuable capacity for making sketches. This book is a very welcome proof of the fact that the study of weather still offers a field for individual enterprise even when, and indeed because, the instrumental equipment is of the best.

That is the first good reason, and I express it with no little sense of gratitude to Mr. Clarke for his spontaneous activity and all that it has meant for the vitality of the study of weather among those of us who have had to work in the seclusion of Victoria Street and South Kensington.

Secondly, in making selections from his store of excellent photographs and sketches, Mr. Clarke has been careful to fit them into the scheme of International Classification. No one who makes such a collection can be insensible to the failings of anybody else's classification, and yet in such matters the better is very easily the enemy of the good. We make more progress by illustrating a classification that is generally accepted than by devising a new one that in the first instance can only form a subject of discussion.

Thirdly, there are the interest and the excellence of the illustrations which Mr. Clarke has chosen and the plain words with which he has introduced them. They are full of suggestion, and, in spite of the transitory nature of the fabric with which it deals, the book is a

substantial addition to the growing edifice of the study of weather.

Some years ago, when I had finished a book on forecasting weather, I realised that it was incomplete because, among other reasons, the study of clouds was not included. Mr. Clarke's book remedies that omission, and I will ask the gentle reader of that work to regard it in that light. I do not wish to add anything to what Mr. Clarke has said, and the only thing that I notice that I should like to subtract is that at the top of a cyclone air passes from low pressure to high pressure, just opposite to what it does at the bottom. I know many people think so, and some have said so, but frankly I do not believe it does—the bottom is the bottom and the top, if there is one, is the top, and not a negative bottom.

NAPIER SHAW.

METEOROLOGICAL OFFICE,
10*th January*, 1920.

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SECTION I

CHAPTER I.

THE OBSERVATION OF THE CLOUDS.

Cloud observation must have commenced at a very early period in the history of mankind. It is only when we consider how deep an impression must have been made upon the mind of early man by the gorgeous hues of sunset or by the gloom and terror of the thunderstorm, that we fully realise how natural it was for him to associate such glories and such terrors with a deity who had to be propitiated. Throughout the whole range of pagan mythology we meet with gods of the sky and air, of light and darkness, and of storm and thunder; gods who were believed to control the rain and deluge, whose beneficence was shown by the sending of fertilising showers, and whose kindling anger materialised in hail and thunderstorms. One of the most effective of the apotheoses in the old Norse mythology is that of Frigga, the wife of Odin and goddess of the clouds, who is pictured dwelling in Fensalir, the Hall of Mists, where she employed her time with wheel and distaff spinning the golden threads which were woven into bands of brightly coloured cloud.

The references that are made to the clouds in the Book of Job and the Psalms prove that, in Biblical times, these wonderful appearances in the heavens had aroused among the Jews a spirit of admiring and reverential contemplation, a spirit which has lasted through the ages

in all lands, and which has been the inspiration of much that is beautiful both in poetry and in prose, as well as in painting. The early half of the nineteenth century saw the genius of Turner applied in art to the delineation of magnificent skies—skies in which the cloud *forms* as well as their glories were for the first time correctly rendered—and it also saw with what reverence and in what glowing language the clouds could be described by John Ruskin in the chapters devoted to them in "Modern Painters".

The same period was likewise noteworthy for the fact that for the first time in this country an attempt was made on scientific lines to classify clouds according to their forms. There can be no doubt whatever that the recognition of certain cloud-formations must have been almost coeval with man's first observations of the skies. In particular the shepherds of the plains and the tillers of the soil must have come to recognise that one form of cloud brought to them rain while other forms did not; and they that "went down to the sea in ships" must soon have become familiar with clouds that gave them windy weather, and with others that presaged coming storms. Shakespeare, in "Richard II," says

> Men judge by the complexion of the sky
> The state and inclination of the day,

and the whole of our household words and maxims about the weather, such as "a red sky at night is the shepherd's delight," are simply the natural outcome of man's powers of correlating certain facts with certain appearances of the sky.

The fact that cloud-forms fell into three broadly distinct classes was the basis upon which Luke Howard

in 1803 suggested the first definite classification of clouds. He recognised, as almost any observer of the heavens could scarcely fail to do, that sometimes the clouds were very light and wispy, spread in lines and patches with a texture resembling hair; at others they were heaped up into mountainous masses; while a third form was that of a more or less dense sheet or layer of cloud resting on the ground—what we, in fact, call a fog. To the first type he gave the name of *cirrus* (from the Latin word meaning "a wisp of hair"); to the second he applied the name of *cumulus* (meaning "a heap"); while the third was called *stratus*, because it was spread out in a flat sheet. It is upon these three type-names that all subsequent classifications have been built up. Naturally there are many forms of cloud intermediate between the main types above-mentioned—Howard himself recognised and gave names to several—and it is precisely this fact which has given rise, since Howard's time, to quite a number of different classifications. Prominent among the more recent of these schemes of classifying cloud-forms is that suggested by the Rev. W. Clement Ley in his book "Cloudland" which appeared in 1894. In the same year a meeting of the International Meteorological Committee, held at Upsala in Sweden, entrusted to Prof. H. H. Hildebrandsson of Upsala, M. L. Teisserenc de Bort of Paris, and M. A. Riggenbach of Zurich, the publication of an Atlas wherein, in accordance with the resolutions adopted at a previous meeting in Munich in 1891, the cloud-forms should be clearly defined and illustrated. The Atlas was published shortly afterwards, and since then a second edition has appeared in 1910. This classification, which is based upon the suggestions of the Hon. Ralph Abercromby and Prof.

Hildebrandsson, is still in use at Meteorological Stations in all countries, and thus serves the very useful purpose of maintaining uniformity in cloud observation throughout the world. The bases of its nomenclature are the heights and forms of the clouds, and ten types are recognised and are given definite names; in addition to which there are four qualifying adjectives applicable to certain forms. The descriptions given and the pictures shown are of very typical character, such indeed as are not likely to be met with at all frequently by observers; and this fact has been instrumental in calling forth further suggestions, mainly tending towards a multiplication of types. In his beautifully illustrated book "Cloud Studies," which appeared in 1905, A. W. Clayden has divided each of the International cloud-types into several sub-types. But this procedure, in addition to making the classification unwieldy, is open to the further objection that, particularly in the case of cirrus, the same cloud-band may contain several of these sub-types within its length simultaneously, and, owing to the rapid internal changes which often characterise these clouds, one sub-type may be transformed into another and then perhaps return to its original form all within the space of a few minutes. In fact, it may be said that so endless are the possible varieties of the clouds, and so bewildering their changes of form, that no classification which was based upon form alone could ever hope to be complete, and it would be advisable rather to aim at a further simplification of the present classification than to extend it.

It may be that in the near future, the work that has been done in the way of investigating the upper air and clouds by aeroplane will provide us with a new basis

whereon we may re-classify our clouds, possibly according to their physical relationships, but meantime, as the International Classification is still regarded as the standard one for observers, it will be well to set it forth at length in the next chapter.

CHAPTER II.

THE INTERNATIONAL CLASSIFICATION.

THE International Classification divides clouds into two main sections according to whether (*a*) they are detached clouds with rounded upper outlines, types that are most frequent in dry weather, or whether (*b*) they are clouds of great horizontal extent, suggesting a layer or sheet, the form most common in wet weather. Then again it divides the clouds into upper, intermediate, and lower classes according to their heights. Classes are set apart for clouds which are known to be caused by diurnal ascending currents, because these clouds have special characteristics of their own, such as great vertical depth; and also for high fogs, which are really the lowest of clouds.

The complete scheme then stands thus :—

A. *Upper Clouds*, average altitude 9000 metres (about 30,000 feet).

(*a*) 1. Cirrus.

(*b*) 2. Cirro-stratus.

B. *Intermediate Clouds*, between 3000 and 7000 metres (10,000 and 23,000 feet).

(*a*) 3. Cirro-cumulus.

4. Alto-cumulus.

(*b*) 5. Alto-stratus.

C. *Lower Clouds*, below 2000 metres (7000 feet).

(*a*) 6. Strato-cumulus.

(*b*) 7. Nimbus.

D. *Clouds of Diurnal Ascending Currents.*

(*a*) 8. Cumulus: height of base 1400 metres (4500 feet), top 1800 metres (6000 feet).

(*b*) 9. Cumulo-nimbus: height of base 1400 metres (4500 feet), top 3000 metres to 8000 metres (10,000 feet to 26,000 feet).

E. *High Fogs*, under 1000 metres (3000 feet).

10. Stratus.

The definitions and descriptions given of the cloud-forms are as follows, the letters within brackets after the cloud names being the recognised contraction for the name:—

1. *Cirrus* (*Ci.*). *Detached clouds of delicate and fibrous appearance, often showing a feather-like structure, generally of a whitish colour.*—Cirrus clouds take the most varied shapes, such as isolated tufts, thin filaments on a blue sky, threads spreading out into the form of feathers, curved filaments ending in tufts; they are sometimes arranged in parallel belts which cross a portion of the sky in a great circle, and by an effect of perspective appear to converge towards a point on the horizon, or, if sufficiently extended, towards the opposite point also. Cirro-stratus and Cirro-cumulus are also sometimes arranged in similar bands.

2. *Cirro-stratus* (*Ci. St.*). *A thin whitish sheet of clouds sometimes covering the sky completely and giving it only a milky appearance* (*it is then called Cirro-nebula*), *at other times presenting, more or less distinctly, a formation like a tangled web.*—This sheet often produces halos around the sun or moon.

3. *Cirro-cumulus* (*Ci. Cu.*), *Mackerel Sky. Small globular masses or white flakes without shadows or*

showing very slight shadows, arranged in groups and often in lines.

4. *Alto-cumulus* (*A. Cu.*). *Larger globular masses, white or greyish, partially shaded, arranged in groups or lines and often so closely packed that their edges appear confused.*—The detached masses are generally larger and more compact (resembling Strato-cumulus) at the centre of the group but the thickness of the layer varies. At times the masses spread themselves out and assume the appearance of small waves or thin slightly curved plates. At the margin they form into finer flakes (resembling Cirro-cumulus). They often spread themselves out in lines in one or two directions.

5. *Alto-stratus* (*A. St.*). *A thick sheet of a grey or bluish colour, sometimes forming a compact mass of dark grey colour and fibrous structure.*—At other times the sheet is thin, resembling thick Cirro-stratus, and through it the sun or moon may be seen dimly gleaming as through ground glass. This form exhibits all changes peculiar to Cirro-stratus, but from measurements its average altitude is found to be about one-half that of Cirro-stratus.

6. *Strato-cumulus* (*St. Cu.*). *Large globular masses or rolls of dark clouds often covering the whole sky, especially in winter.*—Generally Strato-cumulus presents the appearance of a grey layer irregularly broken up into masses of which the edge is often formed of smaller masses, often of wavy appearance resembling Alto-cumulus. Sometimes this cloud-form presents the characteristic appearance of great rolls arranged in parallel lines and pressed close up against one another. In their centres these rolls are of a dark colour. Blue sky may be seen through the intervening spaces, which are of a much lighter colour. (Roll-cumulus in Eng-

land, Wulst-cumulus in Germany.) Strato-cumulus clouds may be distinguished from Nimbus by their globular or rolled appearance, and by the fact that they are not generally associated with rain.

7. *Nimbus* (*Nb.*), *Rain clouds. A thick layer of dark clouds without shape and with ragged edges, from which steady rain or snow usually falls.*—Through the openings in these clouds an upper layer of Cirro-stratus or Alto-stratus may be seen almost invariably. If a layer of Nimbus separates up in a strong wind into shreds, or if small loose clouds are visible floating underneath a large Nimbus, the cloud may be described as *Fracto-Nimbus* (Fr. Nb.), ("Scud" of sailors).

8. *Cumulus* (*Cu.*), *Wool-pack clouds. Thick clouds of which the upper surface is dome-shaped and exhibits protuberances while the base is horizontal.*—These clouds appear to be formed by a diurnal ascensional movement which is almost always noticeable. When the cloud is opposite the sun, the surfaces facing the observer have a greater brilliance than the margins of the protuberances. When the light falls aslant, as is usually the case, these clouds throw deep shadows; when, on the contrary, the clouds are on the same side of the observer as the sun, they appear dark with bright edges. True Cumulus has well defined upper and lower margins, but in strong winds a broken cloud resembling Cumulus is often seen, in which the detached portions undergo continual change. This form may be distinguished by the name *Fracto-cumulus* (Fr. Cu.).

9. *Cumulo-Nimbus* (*Cu. Nb.*), *the Thunder-cloud; Shower cloud. Heavy masses of cloud rising in the form of mountains, turrets, or anvils, generally surmounted by a sheet or screen of fibrous appearance* (*false Cirrus*), *and having at its base a mass of cloud similar to Nimbus.*

—From the base local showers of rain or snow (occasionally of hail or soft hail) usually fall. Sometimes the upper edges assume the compact form of cumulus, and form massive peaks round which delicate "false cirrus" floats. At other times the edges themselves separate into a fringe of filaments similar to cirrus clouds. This last form is particularly common in spring showers. The front of thunder-clouds of wide extent frequently presents the form of a large arc spread over a portion of a uniformly lighter sky.

10. *Stratus* (*St.*). *A uniform layer of cloud resembling a fog but not resting on the ground.*—When this sheet is broken up into irregular shreds in a wind, or by the summits of mountains, it may be distinguished by the name *Fracto-stratus* (Fr. St.).

To the above definitions are appended a few qualifying remarks upon certain variations likely to be met with when observing the clouds. These are:—

(*a*) During summer all low clouds tend to assume forms resembling cumulus. In such cases they should be noted as *Stratus* or *Nimbus cumuliformis*.

(*b*) At times a cloud may present a mammillated lower surface. This appearance should be noted under the name of *Mammato-cumulus*.

(*c*) The ovoid form with sharp edges assumed by certain clouds, particularly during the occurrence of *sirocco*, *mistral* or *föhn*, should be designated *lenticularis*. For example, *Cumulus lenticularis*, *Stratus lenticularis*. Such clouds frequently show iridescence.

The distribution of the clouds according to the heights assigned to them in the International Classification is shown in diagrammatic form in Fig. 1. The diagram is intended to represent the heights of three well-known mountains; in the background is Mount

Fig. 1.—Diagrammatic representation of cloud-heights.

Everest, 29,000 feet high, in the middle distance stands Mont Blanc, 15,800 feet high, while in the foreground is the highest mountain in the British Isles, Ben Nevis, 4400 feet in altitude. Across these mountain peaks, at the levels where they are on the average found, are shown the various cloud-types, the cirrus and cirro-stratus just level with the summit of Mount Everest, and Ben Nevis below all but the stratus. There is, of course, no clearly-defined level to each type such as is shown in the diagram, because in actuality one cloud-type merges gradually into another; cirro-stratus may be found as much lower than its average height as alto-stratus may be found higher than its own normal level; while nimbus may at times be found no higher than stratus. The diagram is so arranged that clouds which show forms intermediate between them are placed vertically over each other; thus cirrus often gives place to cirro-cumulus, which in turn may become alto-cumulus, while the latter frequently develops into strato-cumulus.

Perhaps the most striking feature of the diagram is the relative size of the cumulo-nimbus; the drawing shows, far better than any description, how very unique this type of cloud is when well developed. Other cloud-layers may at times be one or two thousand feet thick, but a cumulo-nimbus with its base no higher than four thousand feet may tower upwards to fifteen or even to twenty thousand feet, thus becoming an actual mountain of condensation.

The vertical shading below nimbus and cumulo-nimbus is intended to represent falling rain, and the anvil-shaped addition at the top of cumulo-nimbus represents the "false cirrus" which frequently accompanies these clouds.

CHAPTER III.

CLOUD-FORMS AND TRANSFORMATIONS.

One of the chief attributes of *Cirrus* cloud is its liability to appear arranged in long bands. Very often after a spell of two or three days of cloudless blue sky the first clouds to appear on the southern horizon are a few faint threads of delicate white cirrus. As time goes on these threads increase in quantity until they spread themselves right across the sky in a series of bands which seem to proceed from one particular point on one horizon, and to converge again towards another point diametrically opposite the first one. The bands are, of course, strictly parallel to each other, but the fan-like arrangement is due to the effect of perspective. Those who are not familiar with the laws of perspective will find them very clearly explained and demonstrated by Ruskin in his chapters on clouds in "Modern Painters"[1]; and their effect upon the appearance of cloud-bands is shown in Figs. 2 and 3 in the present work. Not only cirrus but practically all the detached clouds from strato-cumulus upwards exhibit this banded arrangement occasionally; and in the case of cloud-layers which are striated or waved along the lines of divergence, the effect of perspective is to create widely-differing appearances in the bands according to the apparent inclination of the bands to the vertical. For example, in Fig. 2

[1] J. Ruskin, "Modern Painters," Vol. V, Part VII, chap. ii.

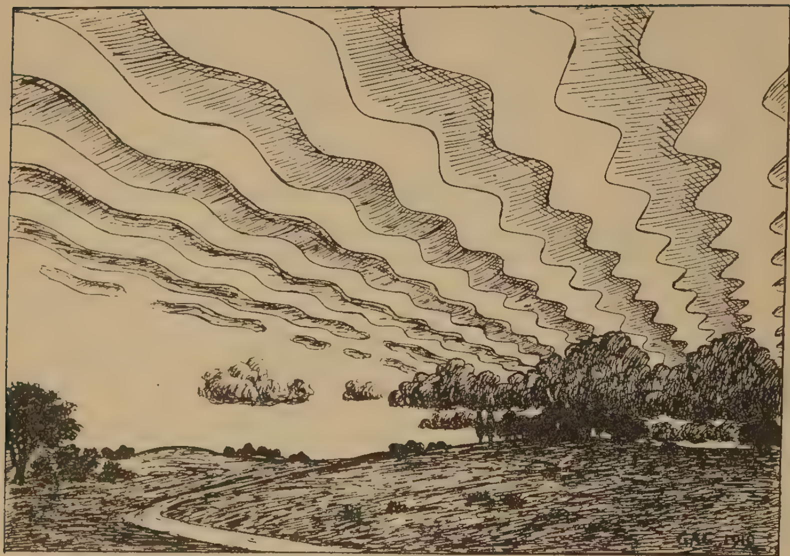

FIG. 2.—Radiant-point: effect of perspective on waved cloud-bands.

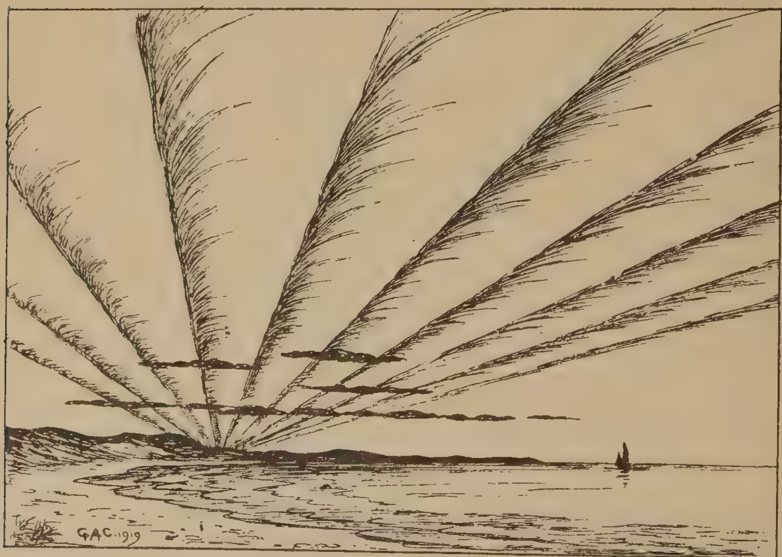

FIG. 3.—Radiant-point: effect of perspective on straight bands with cross-striations.

there is shown a very idealised example of strato-cumulus, where gently but regularly waved bands are separated by spaces of sky of exactly the same width as the bands themselves. The bands are diverging from a point on the horizon exactly on the right-hand margin of the picture, and it will be seen at once that the undulations of the bands become more cramped together the nearer they are to the horizon, and also the more nearly the bands approach the vertical. In Fig. 3 there are shown some bands of cirrus having a feather-like structure, radiating from a point nearer to the centre of the picture. In this case the effect of perspective is to alter very considerably the angle which the curved filaments make with the band itself. Several still more complicated effects are given by Ruskin in the work referred to. A knowledge of these laws is very useful, because an observer familiar with them is able to trace this "Radiant-point," as it is called in meteorology—or "Vanishing-point," as it is called in perspective—even when the cloud-bands are considerably broken up and rather irregular.

When the bands of cirrus are examined in detail it is amazing to see what a variety of intricate yet orderly structure they show. Sometimes, indeed, they consist of a multitude of the very finest of thread-like fibres which singly would be almost invisible, but which when grouped together give a somewhat indefinite and hazy appearance to the whole band; this is the form which so readily coalesces into a sheet and develops into cirro-stratus (Plate 10 A). But much more frequently the cirrus bands are composed of small filaments seemingly inextricably tangled, or of little tufts with tapering extremities, sometimes called "tufted" or "tailed" cirrus. Occasion-

ally a regular series of these tufts may have their "tails" lying in parallel curves which unite into one long band, the whole arrangement then resembling a gigantic feather. Another recurring form is that wherein a strongly defined thread becomes a core round which are grouped many fainter filaments; this form frequently assumes a rippled appearance strongly resembling small wavelets on water looked at from above (Plate 12 B). This last form is called "change cirrus" by Clayden,[1] and the term is very apt, for the cloud seems to be in a state of continual flux, changing from thread to ripple and back again in the course of a few moments. In fact, all the above-mentioned forms, tufts, plumes, and wavelets seem curiously liable to interchange their patterns, and are often found simultaneously in the sky. Usually they eventually develop into the higher forms of cirro-cumulus. There is, indeed, a type which seems to partake more of the character of cirro-cumulus than of cirrus, where the delicate threads seem to have become gathered up into intensely white little balls or patches (Plate 12 A).

At certain times, not only may cirrus be seen to develop into cirro-cumulus, but there may also be found both types together in the same cloud. Some examples of this are shown in Plates 13 A and B; and in connection with this fact an interesting point has been raised by Captain Cave,[2] who has observed these clouds in the south of England. True cirrus cloud is generally regarded as being composed of tiny ice-crystals while cirro-cumulus is believed to be composed of water-droplets which may

[1] A. W. Clayden, "Cloud Studies," p. 37.

[2] Capt. C. J. P. Cave, R.E., "The Forms of Clouds," Quarterly Journal of the Royal Meteorological Society, January, 1917. Vol. XLIII, p. 66.

be supercooled, but nevertheless still liquid. Captain Cave remarks that it is an easy matter to understand that at such heights, where the temperature is far below freezing-point, cirro-cumulus cloud might very readily become transformed into cirrus by the freezing of the water-droplets ; but it is not so easy to understand how the ice-crystals of cirrus can change into the water-droplets of cirro-cumulus. Yet the latter transformation has been observed at Aberdeen far more frequently than the former, and the fact still requires explanation.

Cirro-stratus.—Cirrus clouds, it has been said, are composed of tiny ice-crystals, and when the cirrus has become cirro-stratus, some very beautiful appearances are produced in the heavens through their agency by the light from the sun and moon. The tiny ice-crystals exist in the form of hexagonal thin plates and needles, and act like prisms, refracting the rays of light that fall upon their faces. Thus are produced a series of optical phenomena, the more common of which are indicated in the diagram, Fig. 4.

The phenomenon most frequently observed is the "*halo of* 22°" as it is termed (*a* in illustration). This is a circle of brilliant light seen round the sun or moon at an angular radius of about 22°. The circle, in the case of the sun, has its inner edge tinged with red quite distinctly, and the outer edge may occasionally show a faint tinge of greenish-yellow, but usually this colour is liable to be merged into the general milky tint caused by the white cirro-stratus overspreading the blue of the sky. When the moon is the source of light, the halo is most frequently colourless, but when an exceptionally fine lunar halo is observed the inner edge of the ring is of a dull orange-red tint. Occasionally, but much more

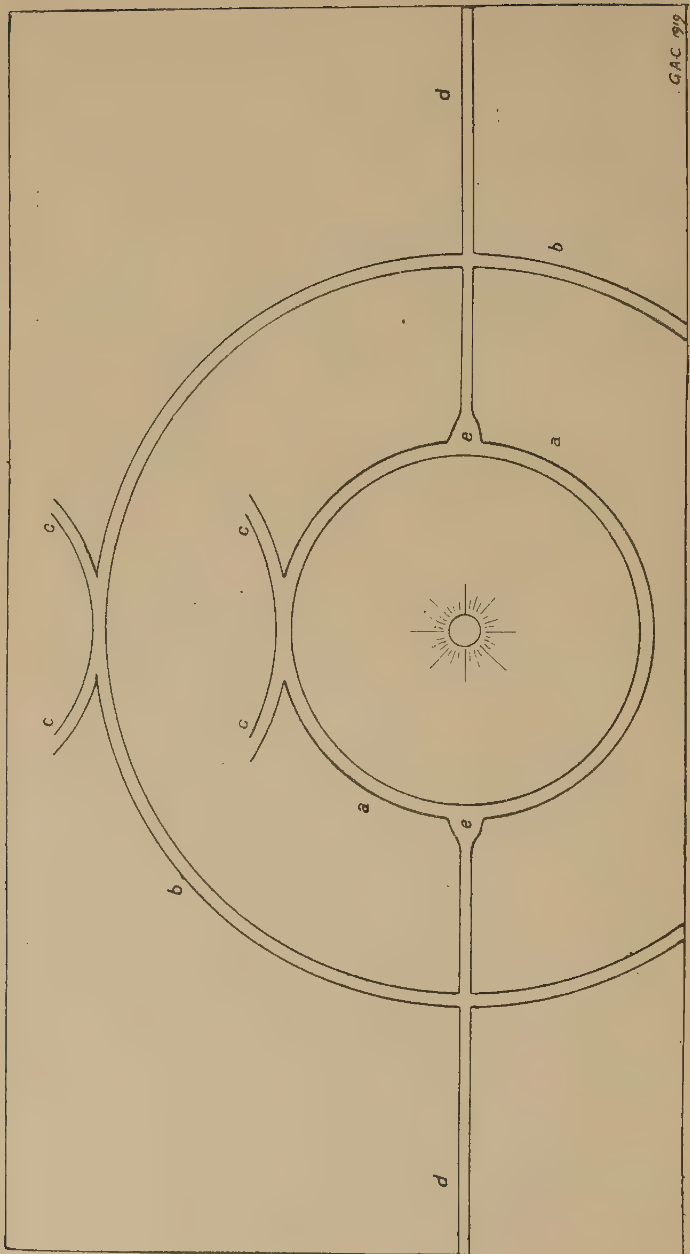

Fig. 4.—Diagram of some optical phenomena.

rarely, there is seen a larger halo, of 46° radius (*b* in figure), but this ring is much less bright than the smaller halo, and usually colourless. If colour is present the inside edge of the ring is red, as in the case of the smaller halo. Both of these halos may have at the top of the circle and in contact therewith portions of other circles which are called *arcs of contact* (*c c* in figure). These arcs are usually very bright where they unite with the halo and they likewise have the red colour on the edge nearest the sun. It is not by any means uncommon to find the arcs of contact visible even though there be no halo apparent, in fact the arc of contact to the large halo of 46° is more frequently seen than is the halo itself, probably because this arc of contact is often very brilliant and strongly coloured, much more so, indeed, than even the smaller halo is. In the coloured picture (Plate 2) this arc is shown without the halo of 46° being present. Arcs of contact are not limited to the upper part of the halo circles; they may be formed also at the lower parts, and even at the sides of the halos, but are very seldom seen. In addition to these two halos there is sometimes seen a white ring passing through the sun and running right round the sky parallel to the horizon (*d* in figure). It is generally termed the *mock sun ring*, because on it at several points may be seen much brighter spots of light, which have been named *mock suns*. Usually there is found one, called the *counter sun*, situated diametrically opposite the actual sun, and sometimes two others at about 60° along the ring on either side of this counter sun.

Mock suns and mock moons (or *parhelia* and *paraselenæ* as they are named) may often be seen even though the horizontal ring is absent. They are most generally

found just outside the halo of 22°, at the points where the horizontal ring if present would meet the halo (*e* in figure), and very frequently they may be seen when no halo at all is present. They are as a rule blindingly bright and strongly coloured, red being, as in the case of the halos, nearest the sun. The most brilliant parhelia seem to be formed in a coarser or lower type of cirro-stratus than that which gives rise to the other halo phenomena, and the same may be said of another optical phenomenon called the *sun pillar* (or *moon pillar*, as the case may be). This is a vertical pillar or band of light, best seen when the sun is very low in the heavens; it is usually of a bright white or golden colour, though occasionally an orange-red one has been seen when the sun has just disappeared below the horizon.

The ordinary halos and arcs of contact are, on the other hand, best displayed when the cirro-stratus is very thin and without texture. There are occasions when the whole sky appears of a pale milky or silvery-blue tint, and it would hardly be expected that any cloud were present, but a very brilliant halo demonstrates the presence of a layer of ice-crystals. This form of cirro-stratus is called "cirrus haze," or "cirro-nebula," and is frequently the first stage in the formation of the ordinary type of cirro-stratus, which latter is in this event very uniform in appearance. Sometimes, however, the cirro-stratus shows distinct detail, such as a matted appearance due to the interlacing of twisted fibres, or else a beautiful web-like structure formed by parallel threads lying in two directions; in this latter case it is not uncommon to find in places a denser warp running through the web. Another form is a rather coarse floccular arrangement which really seems to be a stage of

development intermediate between cirro-stratus and cirro-cumulus.

Owing to the circumstances attending its formation cirro-stratus is seldom a cloud of long duration, it is usually the matter of only a few hours before it has developed into, or given place to, the denser and lower alto-stratus; this is because both these cloud-types are associated with depressions, and therefore with rapidly increasing condensation. On the other hand, when cirro-stratus does occur it is very widespread, frequently covering more than half the total area of a depression.

Cirro-cumulus.—Cirro-cumulus is pre-eminently the cloud of beauty. The wonderful regularity shown in the arrangement of its bands and masses, the delicacy of the little cloudlets themselves, and the vastness of their numbers, all combine to invest this cloud with a distinctiveness that compels our admiration.

The close association of cirrus with cirro-cumulus has already been referred to. When an actual transformation of the former into the latter does take place, the cirro-cumulus thus formed is almost always of a very delicate type, the cloudlets being so small as hardly to be visible individually, and generally of an almost transparent whiteness. It has appropriately been named *Cirro-macula* or *speckle-cloud* by Clement Ley (Plate 13 A).

Sometimes all sizes of cloudlets may be seen together in one sheet—those at the edges being the smallest—so that the size of the cloudlet is not necessarily an actual indication of the relative height of the cloud. One rather curious variety is occasionally seen wherein the cloudlets seem to be compound, a series of rather diffuse cloudlets being grouped into an irregular ring, thus

giving a "rosette" form and rather large size to the cloudlets (Plate 16 A).

The waved forms of cirro-cumulus are equally as beautiful as the globular ones, and when well-developed are even more striking in appearance (Plate 16 B). The waved form appears to be more commonly met with when the cirro-cumulus is arranged in long bands, while the globular type is usually found in irregular patches or sheets of cloud, but even in the latter case there is often to be distinguished an undulatory arrangement in one direction or even in two directions which are frequently nearly normal to each other (Plate 15 A).

Cirro-cumulus appears, from observations at Aberdeen, to be a cloud of remarkably rapid formation, and the same remark has been made by Clayden,[1] who has observed them in Devonshire. In a clear blue sky there may suddenly appear and rapidly develop patches and extensive sheets of a uniform dazzlingly white cloud resembling cirro-stratus, but much whiter and more solid-looking, and after the lapse of some little time they will be seen to break up at the edges into flakes or globular cloudlets of the cirro-cumulus type, and before very long the whole sky may be overspread with a layer of ordinary cirro-cumulus. One such development seen at Aberdeen commenced about 9 a.m. and was not complete till nearly three hours later, but this was an exceptional case; it is usually a matter rather of minutes than of hours for the development to become complete.

In cloud-sheets composed of cirro-cumulus, and also in those formed of the higher and thinner varieties of alto-cumulus, there may be seen round the sun or moon

[1] Clayden, "Cloud Studies," p. 57.

a strongly coloured circle, which is almost always of considerably smaller diameter than the halo seen in cirro-stratus. It is caused by the diffraction of the rays of light by the small particles of the cloud, which latter has therefore been argued to consist of minute water-drops, and not of ice-crystals as in the case of the cirro-stratus. The colours of the *corona*, as this ring is termed, are very evident, and follow in the reverse order from those of the halo. In the corona violet is nearest the sun and is followed by the other colours of the spectrum, blue, green, yellow, orange, and red, the last-named being on the outside of the ring. Sometimes, when the conditions are favourable, a second, or even more frequently repeated ring, showing the colours generally from green to red, may be seen following outwards and beyond the first red, thus producing a double, or multiple, corona. Immediately within the violet of the first corona there is a brownish-coloured ring which fades gradually into the general whiteness that fills up the space between the coronal ring and the sun (or moon). On a clear night in winter-time, when the moon is high in the heavens, a faint corona is occasionally seen without any cloud being apparent, but this fact is indicative of the presence of water-droplets in the atmosphere, and cirro-cumulus is almost certain to appear before long.

Alto-cumulus.—The distinguishing feature between cirro-cumulus and alto-cumulus, according to the International Classification, is that of apparent size and of the liability of the latter cloud to show shadows. But the heavier types of the former cloud do occasionally have faint shadows upon them, especially when densely packed, while the latter cloud, though larger in appearance, is often so thin as to be totally devoid of shadow-detail.

All the various forms of cirro-cumulus, globular, flaked and waved, are likewise to be found in alto-cumulus, and the last-named skies are scarcely less beautiful than those of the cirro-cumulus. It appears to have been these clouds that in their orderly arrangement caused Ruskin such admiring wonder. Calling them the "flocks of Admetus" he one day essayed to estimate the number of cloudlets present in the six bands of cloud stretched across the sky, and found them to be approximately fifty thousand.[1]

When waved patterns of these two cloud-types are seen they are generally called "mackerel skies" in popular terminology, on account of their resemblance in shape to the markings on the mackerel; and the globular or flaked types are sometimes spoken of as "dappled skies".

False Cirrus.—Alto-cumulus may develop from, or succeed cirro-cumulus when condensation is proceeding at successively lower levels, just as alto-stratus follows cirro-stratus, and both these alto-clouds may also be the transformation product of another cloud which will again be referred to when dealing with thunder-clouds and shower-clouds. This cloud is known as "false cirrus" on account of its resemblance to the true or ordinary cirrus. It is not found at the same high level as the true cirrus, being actually only about half as high on an average, but there is reason to believe that it does not differ in actual constitution from the normal type. Captain C. K. M. Douglas, R.A.F., has observed false cirrus from his aeroplane, and considers it to be composed of ice-crystals;[2] Captain C. J. P. Cave, R.E., has ob-

[1] Ruskin, "Modern Painters," Vol. V, Part VII, chap. ii.

[2] Note by Sir Napier Shaw in "Cloud-Forms according to the International Classification," M.O., 233, p. 10.

served in it portions of halos and brilliant mock suns;[1] and at Aberdeen, parhelia, paraselenæ, and sun and moon pillars accompanying false cirrus have been recorded on numerous occasions by the writer. It may be accepted then that the false cirrus is really an ice-crystal cloud, yet on almost every occasion that it has been seen at Aberdeen during the last few years it has eventually become either alto-cumulus or alto-stratus, rather more frequently the former. A very interesting case where the reverse process took place occurred on a day in February, 1919. A sheet of slightly fused but otherwise normal alto-cumulus was moving slowly from S.S.E., and, as it approached, streams of rain or more probably of snow were seen falling from the advancing edge all along its front, while the alto-cumulus itself gradually dissipated. The process continued gradually throughout the whole sheet, with the result that in about an hour the alto-cumulus had disappeared entirely. But the streams of snow, which had fallen vertically at first, seemed slowly to trail out till they took up a position nearly horizontal, and assumed the usual appearance of false cirrus, remaining thus for at least two hours. In this instance the false cirrus was formed at a level somewhat below that of the original alto-cumulus.

There is no very easy rule whereby false cirrus when seen by itself may be distinguished from the true cirrus, nor is it actually important to do so, save as a rough indication of its height, for, as Sir Napier Shaw says, "if an ice-crystal composition be the properly distinctive characteristic of the thread-like structure of cirrus, it only hampers our conception of the atmospheric processes if

[1] Captain C. J. P. Cave, "The Forms of Clouds," "Q.J.R. Met. Soc.," January, 1917, p. 73.

we assume all clouds which show that structure to be at a high level".[1] It would be better perhaps to regard the existence of the cirrus structure as possible through a great range of altitude, and to use the qualification of "false" merely as an indication that the cloud is known or believed to be at an unusually low level. A skilled observer may frequently be able to note several small differences between the appearances of the high true cirrus and of the lower "false" type. The latter is usually denser, or more solid in its appearance; the fibres are not so sharp and clear but somewhat more "woolly" in their texture; the colour of the cloud is frequently cream instead of the pure white of high cirrus; and the cloud is scattered more irregularly over the sky, the banded structure and long radiating lines, which are so characteristic of true cirrus, being very seldom seen in "false" cirrus (Plate 23 A).

Turret-cloud.—A very rare but very important variety of alto-cumulus is met with in thundery weather in summer time. Though it has not been defined and pictured in the International Classification, yet special mention has been made of it by Clement Ley, Clayden, and Cave in their writings, and it is referred to as an additional type in the small cloud atlas issued by the Meteorological Office during the war.[2] The name given to it by Clement Ley was *alto-cumulus-castellatus*, and it is called "turret-cloud" in English on account of its rather unusual appearance, the cloudlets being developed more in the vertical direction than in the horizontal, and closely simulating, though on a very greatly reduced

[1] Sir Napier Shaw, M.O., 233, p. 10.

[2] "Cloud-Forms according to the International Classification," M.O., 233.

scale, the thunder-clouds that so frequently follow their appearance. The turret-cloud is rather sporadic in its occurrence, being seen sometimes in large quantity on several consecutive days and then being absent from the sky for months together. It was unusually plentiful at Aberdeen during the summer months of 1917, particularly during the thundery weather from 13th to 17th July. All through this period the atmosphere was very much stratified, clouds being visible at almost all levels simultaneously, an indication of the very disturbed conditions which resulted in four thunderstorms in the four days. On the 14th, following an early morning thunderstorm characterised by very frequent and vivid lightning, the alto-cumulus-castellatus was very finely developed. Several patches of a very hazy purplish-grey stratiform cloud rapidly formed, and these appeared to have a saucer-like shape, being slightly depressed in the centre. From out of these small sheets there rose up some miniature clouds exactly resembling a large thunder-cloud in shape and general appearance, but they did not last long; rapid changes of form were taking place in them, and they dispersed almost as rapidly as they formed. There seems no reason why they should not be regarded as indicating, though at a very high level, and on a smaller scale, rapidly rising currents of warm air similar to those which form the ordinary cumulo-nimbus clouds that cause thunderstorms, and the importance of recognising this form of alto-cumulus as a special type lies in the fact that it is so frequently followed by weather of an unsettled thundery type.

Lenticular Clouds.—The cirro-cumulus and alto-cumulus clouds are additionally noteworthy because they appear, in certain circumstances, in another form deserv-

ing special mention. In the International Classification one of the notes following the descriptions of the clouds made reference to the "ovoid form" which occurred during sirocco and föhn winds, and gave the word *lenticularis* as its qualifying designation. But beyond mentioning the form, no further description was given, though in reality these lenticular clouds—or rather cloud-banks—differ from all other cloud-formations in one important particular; they are not clouds in the ordinary sense of the term, they are really places in the atmosphere where clouds form and exist for a very short time only. They have been termed "lenticular" from the resemblance of their form to that of the cross-section of a lens. It is only occasionally that a perfectly typical form is seen; more often several cloud-banks are joined together in an irregular mass, but the lenticular or almond-shaped structure is not difficult to recognise even in heavy banks or sheets of the cloud. Their outline has been likened to many forms, to that of an airship, to the shape of the moving sand-dunes in the desert, to tidal sand-banks, and to the wind-blown snow-sastrugi met with in the polar regions and on mountain slopes; all of which forms are of the "stream-line" order.

There are occasions, though they are infrequent, when, instead of lenticular cloud-banks being seen against the blue sky, there will be a continuous sheet of cloud with interstices of a lenticular shape through which the sky is visible, but this reversed order of things occurs in circumstances that are similar in every way to those accompanying the ordinary lenticular clouds. Then again, a combination of both arrangements may be seen, where the central part of a lenticular mass is, as it were, eaten out, thus leaving a resulting cloud-form

that resembles—to quote Sir Napier Shaw[1]—"a large horseshoe as seen from beneath at a great distance". The edges of these cloud-banks are usually rather ill-defined and broken, but the windward edge is sharper than the leeward one, and sometimes may even present a clean-cut outline. In Fig. 5, which gives a sketch of some typical clouds of the lenticular form, the arrow is intended to represent the direction of the wind at the

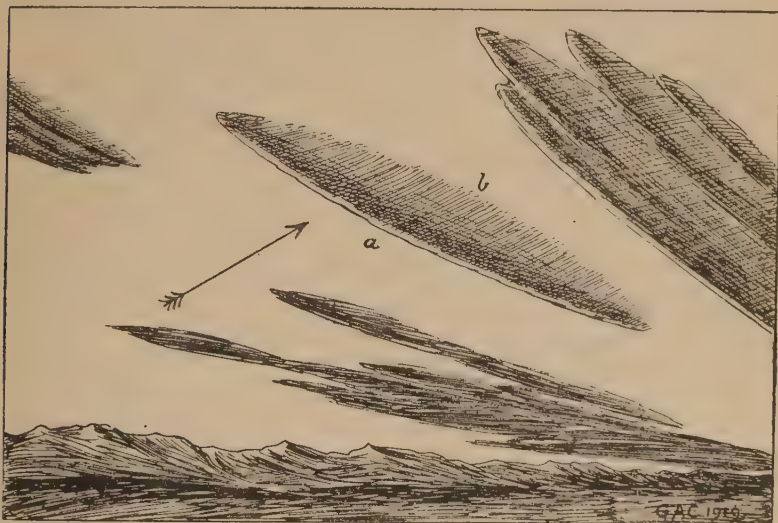

Fig. 5.—The formation of lenticular cloud-banks.

cloud level, and consequently also the direction of movement of the cloudlets which compose the cloud-bank. If one of these lenticular masses be carefully observed, it will be noticed that at the windward edge (*a*) small cloud-flakes are rapidly forming, while at the leeward edge (*b*) other cloud flakes are passing out from the main mass and evaporating. Should the cloud-bank be sufficiently thin, and chance to be so placed as to

[1] Sir Napier Shaw, note in M.O., 233, p. 4.

have the sun or moon behind it, it will be quite possible to watch the cloudlet form at the windward edge, pass right through the cloud-bank and out at the leeward edge, where it rapidly evaporates. Even though the cloudlets themselves may be moving with a high velocity —which as a matter of fact they usually do—yet the cloud-bank may remain practically stationary for a very long time. The cloud-banks shown in Plate 21 A remained in the same part of the sky for over two hours, though the details of their structure were changing rapidly all the time, and on another occasion, a long but quite narrow lenticular cloud was observed to remain stationary for a period of more than three hours, while its component cloudlets were moving rapidly through the mass.

Clouds having the characteristic lenticular form seem to depend partly upon the locality where they are observed, the main local influence being evidently the presence of mountains. The winds referred to in the International Classification, the *mistral* and *föhn*, are both associated with mountains or plateaux. At Aberdeen lenticular cloud-forms are seen at their best during south-westerly to westerly winds, and it is noteworthy that important masses of the Grampians lie to the south-westward and westward of the city ; while Captain Cave,[1] observing the same type of clouds in the south of Hampshire, notes that they are almost exclusively connected with north-westerly winds which come over the South Downs.

An explanation of the cause of these clouds will be given in the next chapter, but meantime a few more

[1] Captain C. J. P. Cave, "The Forms of Clouds," "Q.J.R. Met. Soc.," January, 1917, p. 66.

PLATE 3.

characteristics of the lenticular cloud-banks will be described. At Aberdeen, their presence is associated on almost every occasion with a wind which is strong or high and of a very gusty character, and which shows also a periodic rise and fall in its average velocity. The temperature of the air is very much above the average for the time of year, both in summer and in winter, when these clouds are present, and the barometric pressure is very unsteady, rising and falling alternately at short intervals of time, very much as the velocity of the wind does. In summer the colour of the sky, seen between the clouds, is of a very intense blue; in winter this is not so noticeable, probably on account of the greater amount of surface mist and smoke haze, but at all times of the year the sunrises and sunsets are characterised by an intensity of colouring which is much greater when the sky is covered with lenticular clouds than when the ordinary forms only are present.

On some occasions the lenticular character may be shown only by the cloud at one particular level, but it is far more usual for the sky to show sheets of these clouds at several levels simultaneously, all of them exhibiting the same characteristics of practical immobility of the cloud-bank combined with rapid internal change.

There are times when the lower clouds, such as cumulus and stratus, are seen to assume a somewhat similar lenticular form in *quiet* weather, but in such cases the conditions mentioned above are absent. In some parts of the country this form of stratus is very common and has been popularly termed the "fall cloud".

Alto-stratus.—Alto-stratus, to which reference has already been made when speaking of cirro-stratus, is, when seen in its most typical form, a sheet without any

visible structure, and of a density just sufficient to allow the sun or moon to be seen through it merely as a bright blur, an appearance which has earned for it the popular name of "watery sky," though possibly this name has had its origin rather more in the practically certain rain which is the sequel to the appearance of alto-stratus. When thin, the alto-stratus is sometimes of a yellowish-grey colour instead of the normal bluish-grey, but when very dense it has a dull leaden hue. In addition to being a subsequent development of cirro-stratus, it may also be formed by the fusion of masses of false cirrus, while a third source of origin is to be found in the heavy sheets of cirro-cumulus which frequently move from the westward and which sometimes lose their normal appearance by becoming fused into a continuous and almost uniform sheet. In these last two cases, the alto-stratus is not often structureless; careful observation may usually discover in it a slightly ribbed or reticulated pattern, and occasionally its under-surface is very finely rippled, or exhibits the appearance known as "mammillation," that is to say, that small dome-like or partly globular pendent masses are hanging, very much like inverted small cumulus, from the under-surface of the cloud-sheet.

Strato-cumulus.—Strato-cumulus, which is in reality only a much heavier and lower variety of alto-cumulus, shows all the main characteristics of the latter type, but is much more irregular in its form. Huge waves or bands of strato-cumulus are sometimes met with which must be many miles in length, and which may be separated by intervals of one or two miles (Plate 27 B) and yet exhibit a wonderfully parallel arrangement in the bands; but much more commonly the strato-cumulus appears as a vast sheet of heavy cloud broken up into

isolated masses by an irregular system of lanes (Plate 25 B). At times the waves or bands appear to be composed of one solid mass of condensation, while at others they seem to be built up by the massing together of a large number of smaller flakes (Plate 26 A), this latter condition being especially well marked when the strato-cumulus assumes the lenticular form. The edge of a sheet of strato-cumulus may occasionally present an appearance resembling the vertical face of a cliff, and Captain Douglas, R.A.F., observing by aeroplane, has met with this "cliff-front" structure even within the cloud-sheet. In one case he relates that the upper surface of the cloud-sheet rose up in an almost sheer step of 700 feet, and that the appearance when seen from above was like that of a tidal bore flowing up a river estuary.

Strato-cumulus is sometimes a subsequent development of cumulus; it has been noticed frequently at Aberdeen that towards evening the cumulus clouds, instead of dispersing as is usually the case, gradually lose their characteristic rounded summit and level base, and flatten out into the usual shape shown by strato-cumulus (Plate 30 B). The reverse process has also been observed, though not so often, and when it did occur, it was generally during a spell when the cloud character changed from cumulus during the day to strato-cumulus at night, becoming cumulus again during the following morning.

Nimbus.—It is doubtful whether Nimbus, the next type of cloud mentioned in the International Classification, should really be considered as a type at all. Its essential feature—steadily falling rain or snow—is found to accompany several cloud-sheets of quite different

types. The rain-cloud of a cyclone, the heavy thick layer of formless cloud with steady rain, is certainly a form of cloud that could not be assigned to any of the other groups mentioned in the above classification, but then the rain may cease without any other alteration taking place in the cloud-layer for often a very long time. On the other hand, steady rain often falls from clouds that show distinctly the cumulus form, and more or less continuous rain is frequently produced by the degraded remains of cumulo-nimbus. The matter is further complicated by the fact that the "nimbus" may consist of more than one cloud-layer, as was demonstrated on several occasions during the war when the searchlights were in operation at night. One evening during a slight but steady drizzle the searchlight at Aberdeen revealed the conditions that are shown in the frontispiece. The beam first pierced an exceedingly thin layer of broken "scud" cloud which did not suffice to dim its brilliance, and then entered into a layer of dim nebulous condensation which seemed rather denser in the middle and faded into invisibility both upward and downward. Leaving this layer the beam became almost invisible till it impinged upon the under-surface of a very dense cloud-layer, lighting it up with great brilliancy. The highest layer was probably between one and two thousand feet high, while the misty stratum was about half that height and possibly three or four hundred feet thick. It would appear that the fine drizzle was falling from the misty layer and rendered the searchlight beam brightly visible up to that level, while above it there was no precipitation to be illuminated, and thus the beam became much less bright.

Rain or snow showers have often been seen to fall

from the intermediate clouds of the alto-cumulus and heavy cirro-cumulus types, though such showers evaporate again before reaching the ground, and very frequently there forms below strato-cumulus a thin film of cloud which disperses again after a short interval by falling in a shower of rain. Thus it appears that nimbus may be used as a term embracing many rain-producing clouds of widely differing form or arrangement, and Clayden,[1] who has commented upon the matter in like manner, has suggested the use of the term "nimbus" as a qualifying word rather than as a type.

Cumulus and Cumulo-nimbus.—The clouds of diurnal ascending currents are easily recognisable on account of their great size and massive structure. The dome-shaped heap with a flat base is characteristic of both cumulus and cumulo-nimbus, but the disparity in size between them is very great. The ordinary cumulus of a summer day is only some fifteen hundred feet thick, but cumulo-nimbus clouds continue their growth till sometimes they are four miles deep from summit to base, and may spread over many square miles of country. Their enormous size accounts for the fact that they are best seen when distant, for as they approach, their advancing bases (which, on account of their greater proximity to the observer, and in accordance with the laws of perspective, move at a much greater apparent velocity than do their summits) project forward and hide from view the upper portions of the cloud. The cloud then passes overhead as an intensely blue-black or dull purple sheet, and after the passing of the base, the main cloud mass again becomes visible gradually as it recedes.

Cumulus and cumulo-nimbus clouds are both the

[1] A. W. Clayden, "Cloud Studies," p. 74.

result of the condensation of moisture contained in the rising air-currents which are caused by local heating of the atmospheric layers in contact with the ground. The actual process will be fully described in the next chapter, but it may be mentioned here that the cumulus clouds are formed by the smaller "convection" currents, as they are termed, while the cumulo-nimbus are the production of much more vigorous ascending currents. The flat base of the cloud marks the normal level at which condensation takes place in any particular instance, while the rounded dome and columnar protuberances mark the continued ascent of the convection currents. That these currents may be very powerful indeed is shown by the hailstones that accompany thunder-clouds. Large hailstones when examined show by their internal structure that they are built up of successive layers of ice, which would seem to indicate that the hailstones have been carried up to the upper parts of the cloud several times, receiving each time an additional coating of ice by the freezing of the water they have collected in the lower parts of the cloud. To support the weight of these large hailstones and to carry them up to the great heights sometimes reached by the top portions of cumulo-nimbus, an upward current exceeding twenty miles per hour has been mentioned by Captain Cave[1] as being necessary. The downward air-currents are also often very considerable, and cause great turbulence in the cumulo-nimbus clouds, as may often be witnessed even beneath the cloud-base, where small fragments of cloud may be whirled rapidly downwards and upwards by these currents. Sometimes the downward current,

[1] C. J. P. Cave, "The Forms of Clouds," "Q.J.R. Met. Soc.," p. 74.

especially if accompanied by hail, is seen to carry down with it parts of the base of the cloud, and to cause them to hang in huge bulges below the main mass. This usually occurs in the rear portion of a thunder-cloud or of a hail-squall cloud, and the appearance is termed *mammato-cumulus*.

One special feature of cumulo-nimbus is the development above the domed portion of a mass of condensation which has a shape very closely resembling an anvil, if judged by its profile appearance, but which is really a tabular flat-topped mass, rounded in plan and widest at the top. The edges of this "anvil" are frayed out into the fibrous form associated with the cirrus clouds, and on this account the anvils are said to form the "false" cirrus which has already been described in this chapter. Clouds showing the anvil form (Plates 31 & 32) are usually regarded as the type which gives rise to thunderstorms with hail and rain. This is undoubtedly true, but it is worthy of mention that two severe though short thunderstorms which occurred at Aberdeen within recent years, and which were accompanied by heavy rain and hail, proceeded from clouds which retained their hard rounded outlines without any sign of the anvil form developing. On the other hand, in spring and autumn, a much smaller though still extensive form of cumulo-nimbus is very frequent at Aberdeen, and always shows the anvil structure exceedingly well developed, so much so in some cases that the cloud appears to be almost entirely anvil (Plate 32 A). This particular form is always accompanied by wild squally weather with frequent showers of rain, sleet, and hail.

The gradual growth of the anvil form is shown in the diagram Fig. 6, where there are shown the changes

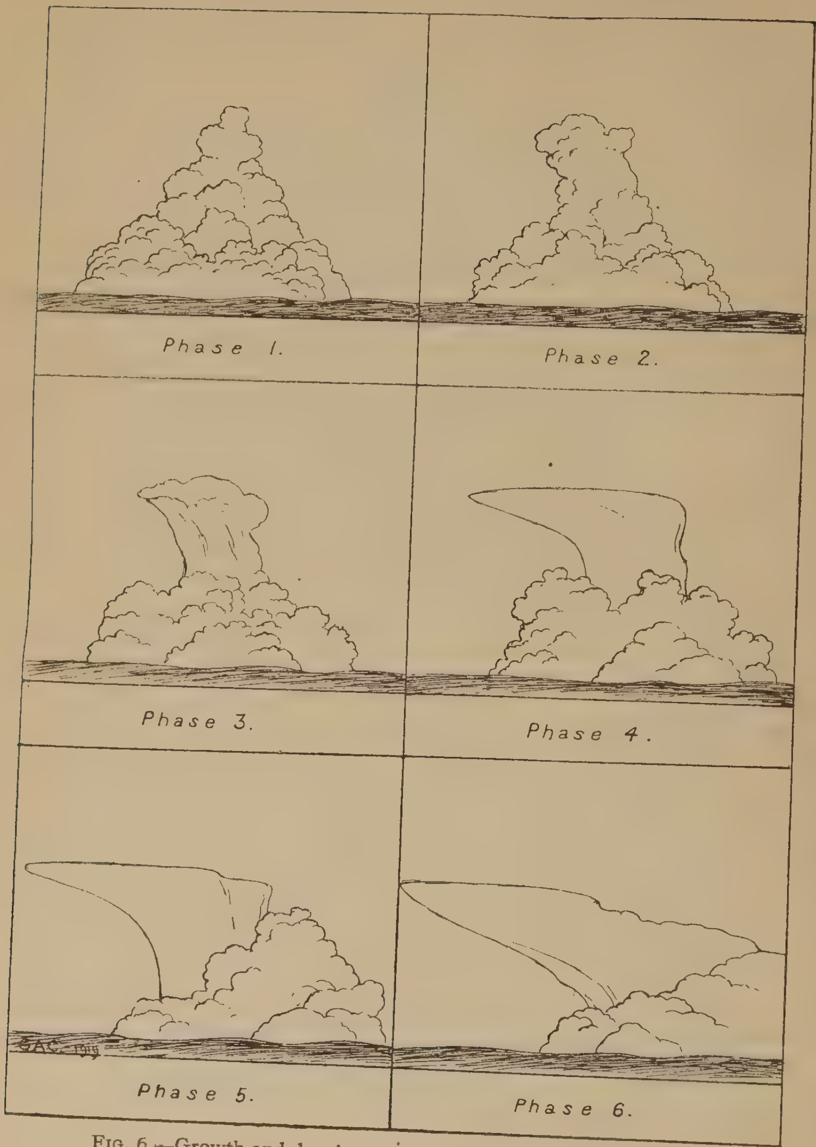

FIG. 6.—Growth and development of a cumulo-nimbus "anvil".

that took place during approximately half an hour in a large cloud, very far distant beyond the horizon, one day in the autumn of 1918. The cloud was moving from west-north-west, that is, away from and a little to the right of the observer, who was looking due east. The anvil will be seen apparently moving slowly to the left, which indicates in reality that the air-currents at the level of its top were more westerly than were the surface ones, and the last phase seems to show that the ascending currents were losing their vigour, since the main mass of the cloud appears flatter in that phase. Altogether the six phases serve to demonstrate how very great may be the changes that can take place in a short space of time, even in the largest clouds.

When, after a period of activity which may extend sometimes over several days, the ascensional currents become more feeble, or cease altogether, the anvils of false cirrus usually become separated from the cumulus mass, and, assuming sometimes the forms of patches of alto-stratus, alto-cumulus, or even of thin strato-cumulus, they may drift away without evaporating, and thus it happens that they may be seen in regions far away from their origin. At Aberdeen these cloud patches often herald the approach of weather similar to that which produced them, particularly when they are moving from the north-north-west.

If cumulo-nimbus clouds become grouped together into a very large mass, as is very commonly the case in thunderstorms, it may occasionally be noticed that the upper portions of the cloud are moving from some southerly point, while the base may be moving from another totally different direction, generally from north-west or north. The cause of this is probably that a

north-westerly air-current, which is considerably cooler than the rest of the air in the neighbourhood, undercuts the southerly one, and in doing so forces up the warmer and lighter surface air, thus increasing the convection currents and consequently also the formation of cloudy condensation. This gives rise eventually to thunder and hail and rain squalls, and the coolness which succeeds the thunderstorm and its previous sultry conditions has been in reality the cause and not the result of the storm, though the process is popularly referred to as "the thunder clearing the air". Such thunderstorms are of the nature of the "line-squall" which will be described later.

An outstanding feature of cumulus and cumulo-nimbus clouds, that which segregates them in a section by themselves, is their liability to appear in greatest quantity at one particular time of the day. During weather when their type is prevalent the early morning may present a sky of cloudless blue, but somewhere between eight and ten o'clock a few small fragments of white cloud appear and increase rather rapidly in size till they become the familiar dome-shaped heap clouds known as cumulus. As time goes on these clouds grow larger and more numerous, till the sky may become almost entirely covered with them. The period of their maximum is usually found to be about two or three o'clock in the afternoon. After this they gradually diminish both in quantity and in size till towards evening, when they may have vanished altogether, leaving the sky once more cloudless. Sometimes the type of cloud may remain cumulus throughout, the heaps growing very little higher, though much more numerous—at times so numerous as to coalesce and completely cover the

sky—but on other occasions they may be seen to increase in the vertical direction and to become cumulo-nimbus. This latter form also may disperse in the evening, but in a different manner. The upper portions of the cumulo-nimbus cloud frequently lose their cumulus form and either flatten out into a sheet or into a number of fragments resembling thin strato-cumulus. In so doing they become detached from the lower parts of the cloud and float away exactly as do the "anvils" of false cirrus, while the basal part of the cloud disperses entirely. It is only comparatively rarely that cumulus clouds are seen during the night-time, though cumulo-nimbus are rather more common, but in all such cases their presence is a sign of atmospheric instability.

The showers which fall from cumulo-nimbus clouds are responsible for the appearance of that most beautiful of all optical phenomena, the rainbow. Rainbows are seen on the opposite side of the observer from the sun, and appear as coloured arcs low on the horizon if the sun be high in the heavens, and becoming higher and more extensive as the sun declines, till they are seen at their greatest extent as semicircles when the sun is just setting. An imaginary line from the sun's disc passing through the head of the observer will, if projected upon the plane of the falling shower, give the centre of the circle of which the rainbow forms an arc. As the angular radius of the primary bow is approximately 42° it follows that no such rainbow can be seen if the sun's angular elevation above the horizon is more than 42°. Occasionally there is seen a "double rainbow," that is, a secondary bow outside the primary one, the angular radius of this secondary bow being approximately 54°. The secondary bow is fainter than the primary and has

the order of the colours reversed. The primary bow shows in ordinary circumstances the complete spectrum from red to violet, the red being on the outside of the circle, followed by orange, yellow, green, blue, and violet in the order mentioned. In the secondary bow the violet is outside and the red inside.

The bows are caused by the refraction and reflection of the sun's rays in the drops of rain. To form the primary bow the ray is first refracted, then reflected once within the raindrop, then again refracted, while in the case of the secondary bow, the first refraction is followed by two reflections before the second refraction occurs. Within the primary bow there are often seen additional narrow bands which immediately follow the violet, and which are known as supernumerary bows; the usual colours of these bands are alternately a faint magenta and dull blue-green. They are caused by the diffraction of light reflected from the drops. The rays which do not follow the path of minimum deviation are also reflected, and produce immediately within the primary bow a general brightness which contrasts very markedly at times with the darker area outside the bow. This difference of tone as well as portions of the additional bands above-mentioned are shown in Plate 35 B.

Originally it was supposed that all rainbows were of the same size, and showed the same colours, but closer observation has proved that slight variations occur in the size of the bow, in the width of the colour bands, in the relative intensity of the various colours, and even in the colours themselves. On one occasion the sequence of colours as observed by Mr. F. J. W. Whipple[1] were

[1] Note by F. J. W. Whipple, M.A., in Meteorological Office Circular, No. 4, Sept., 1916.

as follows—orange, yellow, greenish-blue, indigo, pink, green, pink, neutral tint, pink, the colours following the indigo being presumably the additional bands already mentioned. The sequence of colours depends upon the size of the raindrops which give rise to the bow.[1] In very hazy weather, especially if the sun be low, it is not uncommon for a bow to be seen having no colours other than the red and orange visible; this is due, of course, to the selective scattering of the green, blue, and violet rays of the sun's light by the haze and smoke in the atmosphere.

Rainbows may be formed by moonlight as well as by sunlight, but their colours are much less brilliant than in the case of the daytime bows, being seen usually with difficulty, and often the bow appears colourless.

Stratus.—The lowest type of cloud, known as stratus, is, as its name implies, simply a sheet of condensation. In typical form its appearance is that of a uniform grey pall, usually a little lighter towards the horizon and darker overhead. Beneath it the atmosphere is sometimes excessively clear, objects like ships on the sea being seen at a distance of ten or twelve miles as jet black silhouettes, and as clearly defined as objects near at hand.

At other times there may be a general mistiness of the air between the under-surface of the stratus cloud and the earth. In special cases there may be no definite line of demarcation between the mist and the cloud, and in the extreme case the cloud itself may rest upon the earth, when it is known as a fog. A fog which clears from the surface of the ground by elevation becomes a sheet of typical stratus; the process is remarkably

[1] Pernter, "Meteorologische Optik," p. 540.

common at Aberdeen during spells of sea fog, when at one particular part of the day the town may be shrouded in fog, while an hour or so later everything will be clear below for some little time, with a sheet of stratus covering the sky, only to revert again to the fog condition later on.

Stratus is sometimes an unusually persistent cloud, spells of three to five days of unbroken cloud being not uncommon at Aberdeen. It is during such spells that the remarkable visibility above-mentioned is met with. When stratus sheets break up and disperse they often do so by forming into lumpy rounded masses very much resembling rather flattened cumulus. This is the form to which the International Classification alluded as deserving the qualifying term "cumuliformis" to be added to its type-name. Examples bearing a very close resemblance to cumulus have been seen often at Aberdeen; on one occasion the form was so massive and rounded and showed so flat a base that had it not been seen to form from the stratus it certainly would have been classed as cumulus. Its height was very small, a pilot balloon which was sent up entered the cloud at about eight or nine hundred feet. On other occasions the sheet of stratus separates into masses similar to those of strato-cumulus, and even into long rolls and waves, but usually these masses and waves are so thin that the sun's disc may be seen quite clearly through them (Plate 34 B). Even the largest masses of dispersing stratus are relatively thin. Another method of dispersal is for the sheet to break up into ragged shreds, particularly if the sheet itself has recently been a ground fog, and at other times the cloud separates into very thin wreaths of vapour which, streaming along on the wind, flow in undulating

lines which thus delineate the actual paths of the air-currents in which they are borne.

Detached sheets of stratus are often seen in conjunction with other cloud types. At Aberdeen one of the most common of these occurrences is for a layer of strato-cumulus to have immediately beneath it a stratus film of greater or lesser density; this film may at times give some slight precipitation, as has been already mentioned when dealing with nimbus clouds. Fragmentary stratus is also very common during certain types of weather in winter time at Aberdeen; these will be mentioned in a later chapter. In thundery weather at this station part of the sky may suddenly be covered by an indefinite purplish-grey area of gloom, which is without doubt true stratus; it vanishes as rapidly as it appears, only to form again later on. Another rather more stable form of stratus is found in what appear to be lines, but which are really slightly lenticular patches of cloud floating at several levels simultaneously round the flanks of massive thunder-clouds, to which they give a very distinctive appearance.

The Colours of the Clouds.—The colours of the clouds in daytime are for the most part white and grey, white where the full sunlight falls upon their crests or upper surfaces, and all the most delicate tones of grey in their shadowed portions. In the larger clouds, the grey may become very dark; when it does so it usually shows a slightly bluish tint. In thunder-clouds the white may assume a yellowish or even coppery-red hue, and the darker parts may become purple-grey, this is caused by the soot and smoke or even dust that are carried up into the clouds by the powerful ascending currents which form them.

But when the sun is low in the heavens, as during the daytime in winter, or towards the time of sunset, the white colour of the clouds takes on a golden tinge, which grows deeper and passes through various tones of orange and red as the sun sets, or in the reverse order as it rises. The dust particles and haze in the atmosphere cause a selective scattering of the sun's rays, stopping out those of shorter wave length like the violet and blue, and permitting only the orange and red to pass. This is done all the more effectively because the rays of light from the setting sun are refracted by our atmosphere and pass for a very great distance through the lower layers of the air wherein most of the dust haze is found.

The lower clouds are, of course, the first to assume the ruddy hues of sunset, and it is no uncommon sight to see a sheet of cirro-cumulus still dazzlingly white while the strato-cumulus below is deep orange, but, as time passes, the lower clouds gradually lose their red colour and become deep purple-grey while the sunset hues are transferred to the upper layers. If the cirro-cumulus clouds are high and of delicate structure they become suffused with the most beautiful rose-colour, a tint far purer and more ethereal than is ever to be seen on the lower clouds, and which, when seen against a deep blue sky affords a picture of exquisite beauty.

But the most striking sunsets seen at Aberdeen are those which accompany the presence of the intermediate clouds of the lenticular form. Frequently when these are present there is a narrow belt of cloudless horizon in the west, so that no obstruction is offered to the last rays of the setting sun. Then again, the lenticular clouds themselves have most beautifully rippled under-surfaces,

and this greatly enhances the effect of the colour, for the sky may at times look like one vast inverted sea of flame, or, as Ruskin so beautifully has expressed it, be covered "as with the drifted wings of many companies of angels".[1] And another peculiarity of these lenticular skies is the very long duration of colour that sometimes occurs. One such display—a most extraordinary one—was seen at Aberdeen in January, 1911, when the clouds showed varying colours for over two hours. Shortly before four o'clock in the afternoon the edges of the clouds were outlined in pale gold, which gradually grew more intense until, when the colour became transferred to the under-surfaces of the clouds, they gleamed like polished brass. As time went on the yellow deepened into orange, which in turn flushed into flame colour and scarlet, the open sky beyond the clouds changing at the same time from pure blue to greenish-blue. By five o'clock the clouds were vivid crimson and the sky a clear pale emerald, but the colour display was by no means over, for the clouds continued slowly to deepen in hue till as late as six o'clock when they showed a most wonderful colour, one not easy to describe, an angry red, so deep as to be almost black, yet nevertheless of great intensity. The horizon sky had changed to a dull milky-white hue.

When it happens that, after a spell of rainy weather, the nimbus clouds commence to break up about the time of sunset and to assume a somewhat globular form resembling strato-cumulus there is occasionally to be seen a curious play of colour in them. Separate masses will appear suffused in turn with dull pink, violet, dull

[1] Ruskin, "Modern Painters," Vol. I, Part II, section III, chap. iv.

orange, and even green. The colours are additional to their own greyish hues, and are therefore subdued but are none the less very evident.

Another variety of cloud colouring, which is seen in full daylight, is that known as "irisation". The phenomenon is seen best developed in the higher clouds of the alto-cumulus and cirro-cumulus types, particularly in that form of the latter which is found massed in the oval lenticular sheets having a slightly rippled structure. The colouring is seen at angular distances from the sun varying mostly between 10° and 30°, and also shows a strong tendency to appear along a horizontal line through the sun's disc, though it may also appear elsewhere. The colours shown usually follow the edges or contours of the cloud masses, and are not pure spectrum colours but compounds of these. The commonest are rose-pink and emerald-green, both of which are usually very pure and bright, while yellowish-orange, violet-blue, and greenish-yellow are also more or less in evidence. In fact the iridescence resembles very closely the appearance of mother-of-pearl, and Dr. Simpson[1] has explained it as being due to diffraction effects produced by the various sizes of water-droplets present in the cloud. Dr. Simpson, who accompanied Scott's last expedition, made a special study of the iridescent clouds which were so frequently seen in the Antarctic.

[1] G. C. Simpson, D.Sc., "Coronæ and Iridescent Clouds," "Q.J.R. Met. Soc.," October, 1912.

CHAPTER IV.

SOME CAUSES OF THE FORMATION OF CLOUDS.

Clouds are really the visible products of the condensation of the water-vapour that is always present in the atmosphere. The heat of the sun's rays is constantly evaporating moisture from the surfaces of the sea and the land, and the invisible water-vapour thus produced is absorbed by and diffused in the air. The air will continue to take up water-vapour and the latter will remain quite invisible until a point is reached when the air becomes saturated, and then any further addition of water-vapour results in super-saturation, and the excess of moisture becomes visible as a cloud, provided that there are present in the air some nuclei upon which the condensation can form. As the lower layers of the air always contain a good deal of small dust particles in suspension, the required nuclei are always present there, and it has been demonstrated that ionised air itself may also act in the same way as material nuclei do, so that condensation thus becomes possible wherever water-vapour may exist in sufficient quantity. This sufficiency of quantity varies very greatly. The amount of water-vapour that a given mass of air can contain before becoming super-saturated depends entirely upon the temperature of the air, no other condition affecting it in any way. The surface layers of the air are very much warmer than those above them, as will be explained

later, and the capacity of the air for water-vapour increases at a much greater rate than does the temperature necessary to produce this capacity. At a height of 5 kilometres (or 3 miles) a given volume of air can contain less than one-fifth of the water-vapour that it can hold at the surface, while at double that height the amount of water-vapour present must be less than one-thirtieth of the surface quantity. It follows, therefore, that cloud will be found in greatest quantity usually in the lower layers of the atmosphere, and also that the lower clouds will often be of very great thickness while the higher clouds will, on the contrary, be very tenuous.

If then the air in any part of the atmosphere is saturated, and the temperature falls, the excess of moisture immediately becomes visible as a cloud of water-drops or of ice-crystals. These droplets are of exceedingly minute dimensions, and therefore fall so slowly that even the very feeble circulating air currents within the cloud are sufficient to keep them suspended, and it is not until increasing condensation and the consequent coalescence or enlargement of the drops takes place that the latter fall as rain. But though in calm air the droplets of water fall very slowly, yet they do eventually reach a lower altitude, and there they usually find themselves in either a warmer layer of air, or a less humid one, wherein they are soon evaporated. But meantime fresh drops are condensing in the cloud layer and these cause the cloud to persist as a whole, sometimes for a long period, though its details may vary considerably on account of the incessant condensation and evaporation going on within it.

Modes of Cooling of the Air.—The requisite cooling of the air to produce condensation may be brought

about in several ways : by dynamical cooling, where the rising of the moist air results in its expansion and the consequent lowering of its temperature ; by the turbulence of warm moist air flowing over much cooler surfaces ; by a local or general fall of barometric pressure ; by the mixing of two masses of saturated air of different temperatures ; by the radiation of heat from the layers of air ; and by the conduction of heat from one air-layer to another. Of these processes the first five are the more important, the last one is practically negligible.

1. *By the Rising of the Air.*—There are two methods whereby the moist air may be transferred to a higher level. The first is the forced rising of the warm moisture-laden southerly current by the cooler air currents from the east and north, which all combine to form the circulation found in low-pressure areas. When this takes place, extensive layers of cloud are formed, which eventually become a sheet of nimbus from which the rainfall of the depression is produced.[1] Such cloud usually occurs in a widespread unbroken sheet, which towards its rear edge separates into shreds or else assumes to some extent the form produced by the second of the two possible methods.

The movements of these air-currents depend upon the distribution of pressure at the time. If the barometers at a large number of stations over a wide area are read simultaneously, and the corrected readings are plotted on a chart, then it will be found that, if those stations where readings are practically the same be joined by lines, these lines, which are termed *isobars* (i.e. lines of equal pressure), will exhibit approximately

[1] The process was very clearly explained in a lecture by Prof. V. Bjerknes at the Royal Meteorological Society on 7th November, 1919.

concentric and roughly circular or oval arrangements. At times the central region will show the highest pressure readings, and the distribution is then known as an *anti-cyclone*, while, when the central area shows the lowest pressures, it is called a *cyclone.* Some of the commoner types of pressure distribution are shown in Figs. 16 and 17 in Chapter VI. It is convenient to imagine the anticyclone as a hill and the cyclone as a hollow, because by so doing it becomes possible to imagine a slope from the one to the other. This slope is in reality one of pressure, and the rate of slope is known as the barometric gradient. It is of great importance in weather production, firstly because the steeper the gradient, or in other words, the closer the isobaric lines representing certain definite and regular intervals of pressure are crowded, the more violent will be the wind, and secondly, because the wind direction conforms roughly to that of the run of the isobars. In the northern hemisphere the main flow of the surface air in our latitudes is from the south-westward, and it is found that the wind-currents round a low-pressure area move in a counter-clockwise direction, while round a high they travel clockwise. But there is a slight difference between the wind direction and the run of the isobar in both cases. The surface winds round a cyclone are inclined inwards at an angle of about 30° to the tangent to the isobar, while round the anticyclone there is an outward inclination of about the same amount. In the upper regions, where cirrus cloud is found, this arrangement is reversed, the winds of the cyclone moving outwards, and those of the anticyclone moving inwards (Fig. 7). There is thus shown a movement of air from the high towards the low at the surface, while in the upper air the motion is from low to high, or it may per-

haps be better expressed by saying that the surface air-currents feeding a low-pressure area are convergent, while those associated with a high are divergent.

It is not, however, the same body of air that whirls round a depression in a circle. In actuality masses of air are drawn from different sources round the low pressure area, enter into the system along certain paths and then either die out in the centre by rising, or else pass out of the disturbance again. Shaw and Lempfert [1] have investigated a large number of depressions, and have succeeded in tracing the paths or trajectories of the moving air involved in the disturbances, and the same has been done in the case of the storm of 11th to 13th November, 1915, by Geddes.[2] From the maps of trajectories worked out by Dr. Geddes, Fig. 8 has been drawn. It shows in heavy lines the paths of moving air from 4 p.m. till midnight on the 11th, while in light lines are two other paths from 7 a.m. onwards on the 12th. The crosses on the lines indicate intervals of two hours. The warm south-westerly current which was at a temperature of between 50° and 60° F. may be seen apparently to end in the centre of England, and was evidently forced to rise over the barrier formed by the cold easterly current which had a temperature of from 35° to 45° F. The two trajectories from northward in the rear of the depression may also have originated somewhere to the eastward. During the passage

[1] W. N. Shaw, Sc.D., F.R.S., and R. G. K. Lempfert, M.A., "Life History of Surface Air Currents," M.O., 174, 1906.

[2] Lieut. A. E. M. Geddes, R.E., "The Storm of 11th to 13th November, 1915, in its Passage over the British Isles," "Q.J.R. Met. Soc.," January, 1917.

of the storm the British Isles were practically covered with nimbus cloud which yielded very heavy rain.

The second form of dynamical cooling is that commonly known by the name of "convection," and the agency which produces it is the heating of the surface air-layers combined with the effect of the rate of fall of temperature with height. The forms of cloud produced

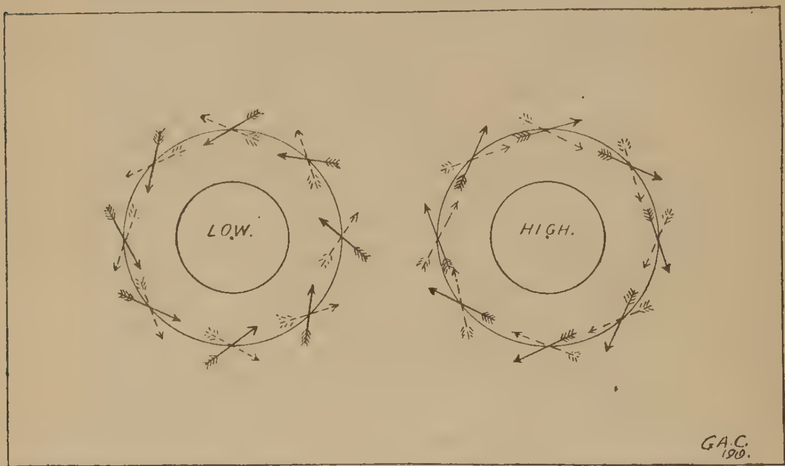

FIG. 7.—Directions of air-motion round low and high-pressure systems. The full arrows show the directions at the surface, while the dotted arrows indicate those at high levels.

by this process are of the cumulus and cumulo-nimbus types, and also include the long extended bank of cloud usually associated with line-squalls.

It is a fact of observation that, taken on the whole, the surface layers of the air are the warmest, and that, as we ascend, the temperature decreases in the layers above, up to a height of about seven miles. If it were possible thoroughly to mix up the whole atmosphere until each layer possessed the appropriate temperature

corresponding to its pressure, it would be found that, provided no part of the air was *saturated* with water-vapour,

FIG. 8.—Map showing the trajectories of air on 11th November, 1915.

the temperature of the air would decrease steadily at a rate of about 10° C. for every 1000 metres of ascent or about $5\frac{1}{2}$° F. for every 1000 feet. This rate is known as the *adiabatic* lapse-rate for dry air. It implies that

if a mass of air at the surface were raised upward without having any other heat communicated to it or withdrawn from it, its temperature would fall at the above-mentioned rate simply on account of its expansion.

But this ideal state of matters does not exist throughout our atmosphere. Irregular heating, condensation of saturated air, convection, radiation and conduction of heat all tend to produce something differing from adiabatic rate. It is not intended in the present work to do more than to indicate the salient facts, as the subject is thoroughly dealt with by Shaw, Gold, Dines, and others.[1] In the actual atmosphere the average fall of temperature with height is found, from the records of registering balloons, to be about 6° C. per kilometre or about 3° F. for every 1000 feet, but the decrease is not regular. For the first 3 kilometres or 10,000 feet the temperature changes are erratic; after a steady fall there will sometimes appear an abrupt rise, known as an *inversion*, which may be as slight as 1° F. and at other times may be as much as 10° F. This rise of temperature is, however, only local and does not extend far; the temperature above it continues to fall off at an increasing rate till at about 7 kilometres or 23,000 feet the rate of fall is greatest, sometimes approaching the adiabatic rate; but when 11 kilometres or 7 miles is reached the fall of temperature abruptly ceases, and the temperature remains practically constant from that point upwards

[1] Sir Napier Shaw, F.R.S., "Manual of Meteorology," Part IV, 1919. E. Gold, M.A., "The International Kite and Balloon Ascents," "Geophysical Memoirs," No. 5, M.O., 210 (e), 1913. W. H. Dines, F.R.S., "Characteristics of the Free Atmosphere," "Geophysical Memoirs," No. 13, M.O., 220 (c), 1919.

as far as balloons have as yet penetrated, which distance is about twice the last-mentioned height. There exists therefore an isothermal layer in the atmosphere at least seven miles deep, superposed upon a layer about seven miles deep wherein changes of temperature with height are very great. On account of the great difference in their physical conditions the isothermal layer has been named the *stratosphere*, while the lower layer is known

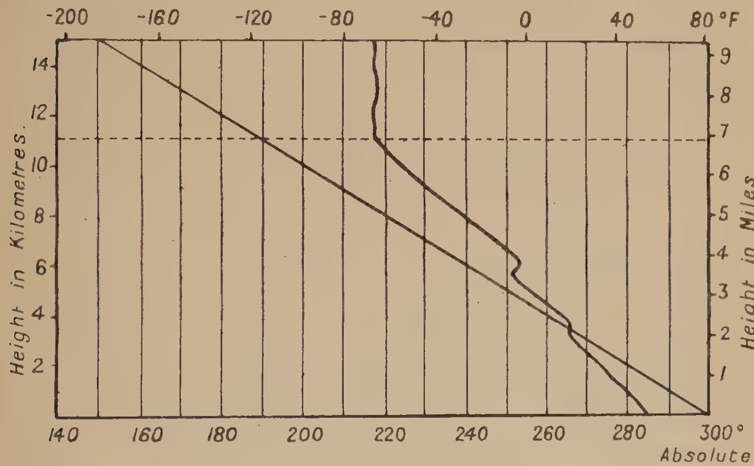

FIG. 9.—Adiabatic lapse-rate (straight line) and an example of vertical temperature gradient in the atmosphere (irregular line). The base of the stratosphere is shown by the dotted line.

as the *troposphere*. The actual conditions in the atmosphere are shown in Fig. 9, wherein the adiabatic lapse-rate appears as a straight line, and the average vertical temperature gradient as an irregular line, showing two of the smaller abrupt "inversions". The height of the commencement of the stratosphere as mentioned and shown here refers to our own latitudes; the height is greater (17 kilometres) at the equator, and lower (8 kilometres) at the poles. This height is important, inasmuch as the cessation of the fall of temperature imposes

a limit upon the possibility of convection in the stratosphere, and therefore clouds are not likely to form there.

In the troposphere, however, the reverse is the case; convection is often very active in the surface layers of the air, and results in the piling up of huge masses of condensation. During bright sunny weather the ground becomes much warmer in some places than in others, and communicates its heat to the air layers in contact with it. These air masses, becoming thus warmer than

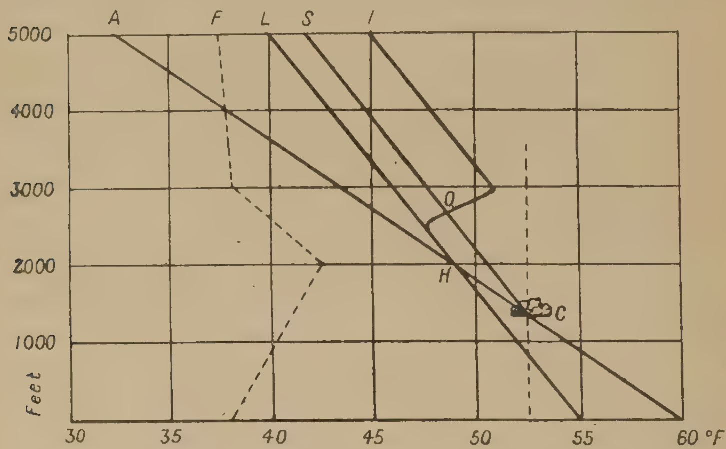

FIG. 10.—Diagram showing lapse-rates and condensation.

the surrounding masses, also become lighter and are therefore forced to ascend. As they ascend they expand and cool down at the adiabatic rate, but their ascent continues until they reach a level where the surrounding air is at the same temperature as that to which they have cooled, after which any further ascent would make them colder and therefore heavier than the surrounding air. How soon this may occur depends upon two factors; the actual lapse-rate in the atmosphere, and the degree of saturation of the rising air. Fig. 10 shows a concrete ex-

ample. The actual lapse-rate is assumed to be 3° F. for 1000 feet and is shown by the line L. The mass of air is taken to be 5° F. warmer than the surrounding air, which latter is at a temperature of 55° F. As the heated air rises, it will follow the line A, which indicates the adiabatic rate for dry air. The two lines meet at the point H and this indicates that the air will rise to 2000 feet and that its temperature will then be 49° F. That is, if the air be dry or at least still unsaturated. But, if the air contained much moisture originally, it will reach a point during the course of its ascent where it will become saturated and the moisture will condense and form a cloud. Suppose that the relative humidity of the air when it leaves the surface is 76 per cent.; then the dew-point for that humidity for air at 60° F. is 52·5° F., and as soon as that temperature is reached, the air becomes saturated and a cloud forms at the level C, where the adiabatic lapse-line cuts the line representing 52·5° F. From this point upwards the air continues rising, but owing to its saturated condition it cools down more slowly, because the heat produced by the condensation of the water-vapour diminishes the rate of cooling; the actual rate at which it does cool is on an average approximately 3° F. for 1000 feet. Now this rate is the same as the average rate of fall of temperature in the atmosphere, and therefore if the average atmospheric lapse-rate were perfectly regular, there would be no point where the saturated lapse-line (marked S) would intersect the line L, and therefore the ascending air would go on rising indefinitely to the top of the troposphere. But the atmospheric lapse-rate is not regular, as may be seen from the dotted line F, which represents an actual lapse-line recorded at South Farnborough. Suppose that at

2500 feet the temperature of the free atmosphere rises abruptly 3° F. and that this inversion makes the lapse-line follow the line I. Then the rising columns of saturated air will be definitely stopped at the level O, because now the rising air is colder and heavier than the air above it, and any further condensation will form as a flattened layer at that level. It is because the saturated air can continue to rise and to condense that the cumulus and cumulo-nimbus clouds are so massive and so deep. The more rapid the lapse-rate in the atmosphere the

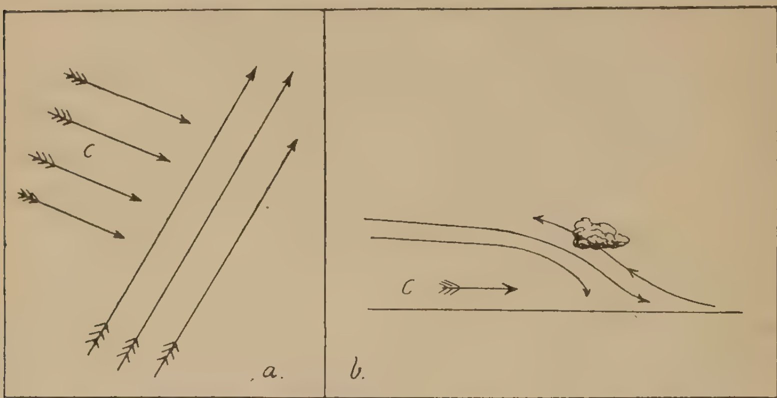

FIG. 11.—Diagrams of air-motions in a line-squall. (*a*) Horizontal plan. (*b*) Vertical cross-section. The cold air is indicated by *c*.

higher the ascending air columns will reach, while if the rate is slow or negative (as shown in the line F), the ascent of the columns will be stopped very early, or prevented altogether. When the lapse-rate in the atmosphere approaches the adiabatic rate of cooling, the atmosphere is said to be in unstable equilibrium, while if the rate is slow, or particularly when it shows an inversion, the conditions are said to be stable.

There is one particular example of the production of cloud by forced convection that deserves special attention; it is the long cloud-belt associated with a "line-

squall". It sometimes happens that when a current of warm air from the south or south-west is flowing across our islands it is invaded on its western side by a cold west or north-west current (Fig. 11 (*a*)). This westerly current is colder and denser than the southerly one, and consequently the latter is forced up by it, somewhat as shown in Fig. 11 (*b*). The forcing-up of the southerly current causes the warm air to expand and cool, and the moisture contained in it condenses in a band of cloud resembling cumulus, which stretches usually in an unbroken line right across the sky, and moves forward with the squall front very much as does the foam on a breaking wave, or the tidal bore up a river estuary. Line-squall fronts often extend over hundreds of miles and are often accompanied by a destructive short squall of wind, a shower, and occasionally by thunder and lightning. The wind veers round suddenly from south to west as the cloud passes overhead, the barometer shows a sudden small rise, and temperature falls suddenly and usually considerably. The records of the meteorological elements in a typical line-squall are shown in Fig. 12.

The structure and theory of line-squalls have been described by Lempfert and Corless,[1] and also by Shaw.[2] Illustrations of the cloud phenomena accompanying the line-squall of 14th October, 1912, at Aberdeen, are shown in Plates 36 and 37, and the following notes were made by the writer at the time of its occurrence:—

"Rain had been falling all the morning until 7 o'clock,

[1] R. G. K. Lempfert, M.A., and R. Corless, M.A., "Line-Squalls and Associated Phenomena," "Q.J.R. Met. Soc.," Vol. 36, pp. 135-170.

[2] W. N. Shaw, F.R.S., Sc.D., "Forecasting Weather," Chapter VIII. 1913.

after which the nimbus cloud cleared away, showing a sheet of grey alto-stratus above. Temperature was rising and stood at 59° F. at 10.20 a.m., and a gentle to moderate wind was blowing from S.S.W. At about 10.24 a.m. a sudden puff of wind followed by sharper

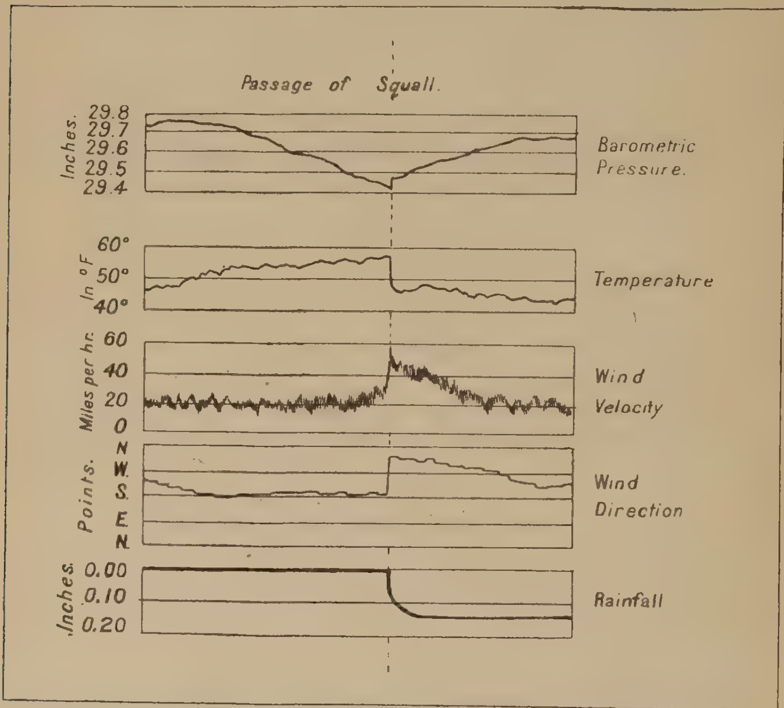

FIG. 12.—Records of meteorological instruments during the passage of a line-squall.

gusts came from the W.N.W., and a patch of cloud formed rapidly in the S.W., lying along a line from S.S.W. to N.N.E. (Plate 36 A). This cloud rapidly extended along its length, moving at the same time quickly towards the E.S.E. By 10.26 a.m. the cloud had become a long band of cumulus cloud stretching right across the sky (Plate 36 B), and was followed in its

rear by a sheet of dark grey cloud. The cloud-band and sheet passed rapidly eastward, and as it reached the coast-line the long band of cumulus gave place to a ragged form. At 10.28 a.m. the cloud-bank had passed out over the sea and almost suddenly a large number of wisps of cloud formed beneath the cloud-bank (Plate 37 A) and rose up rapidly into the main cloud mass. The air over the sea, being moister than that over the land, required less elevation than the latter did to produce condensation when undercut by the cold current. Following the formation of these wisps of cloud, the whole cloud front at 10.30 a.m. appeared, as shown in Plate 37 B, to be a mass of vapour whirling in vortices, while three waterspouts formed over the sea, moving downwards from the cloud but not reaching the water, which latter, however, showed their influence by the disturbance of its surface. At the same moment there came the heavy squall of 53 miles an hour from W.N.W., and the temperature dropped to 48° F., a fall of 11° F. A sharp shower accompanied the squall. To the northward of Aberdeen the squall was evidently heavier, for factory windows were blown in and whirlwinds of dust and dead leaves occurred. After the squall had passed, the upper cloud was seen to be moving from the southwest, so that the influence of the W.N.W. current was felt only in the lower layers of the atmosphere, and the cold current was therefore not very deep."

A pilot balloon sent up during one of these squalls by Dr. Geddes and the writer showed by its trajectory that the air in the rear of the squall cloud was descending at the rate of about four miles per hour, while moving forward simultaneously at 48 miles per hour.

But it does not always happen that the inflow of cold

air is attended by violent squalls. Many cases occur where the velocity of the cold current, though sufficient to undercut the warm air and to cause the line of cloud, is not sufficient to cause anything other than a slight gust. In such cases the cloud formed is less like a breaker, and shows simply as a line of connected cumulus clouds. An example is shown in the coloured Plate 4, where a bank of massive cumulus clouds is moving slowly to seaward, with the usual condensation wisps rising up to meet it.

It is when the atmosphere is in markedly unstable equilibrium that the cumulo-nimbus clouds are formed. A plentiful supply of warm moist air and no check to the ascension of the currents permits the summits of thunder-clouds to rise to very great altitudes, as has already been mentioned. The apices of these clouds at such great heights are at temperatures far below the freezing-point, and though water may become super-cooled to a very marked degree before freezing (Dr. G. C. Simpson mentions water-drops at – 21° F. in the Antarctic), yet freezing usually does occur eventually, and when this occurs the large anvil-shaped tops are formed to these clouds. The anvils consist of snow mixed with ice-crystals and spread out at the edges in fringes of false cirrus. Thunder-clouds of large size are generally built up somewhat in the manner shown in the sectional view in Fig. 13. In front the ascending warm currents move in the direction shown by the arrows at A, while in the rear the air, cooled by the falling rain and hail, descends as indicated at B; and underneath the base of the cloud the opposing currents set up at C the turbulent motion which is rendered clearly visible to the observer by the whirling fragments of broken cloud floating below the


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main mass. The squalls that at times accompany thunderstorms are caused by the descending cooled air at B, and it is also this descending air which gives rise to the mammato-cumulus referred to on p. 39.

2. *By the Turbulence of Warm Air Flowing over Cold Surfaces.*—If warm air flowing from a region of high temperature reaches a region where the temperature of the land or sea is lower than its own, the air layers in

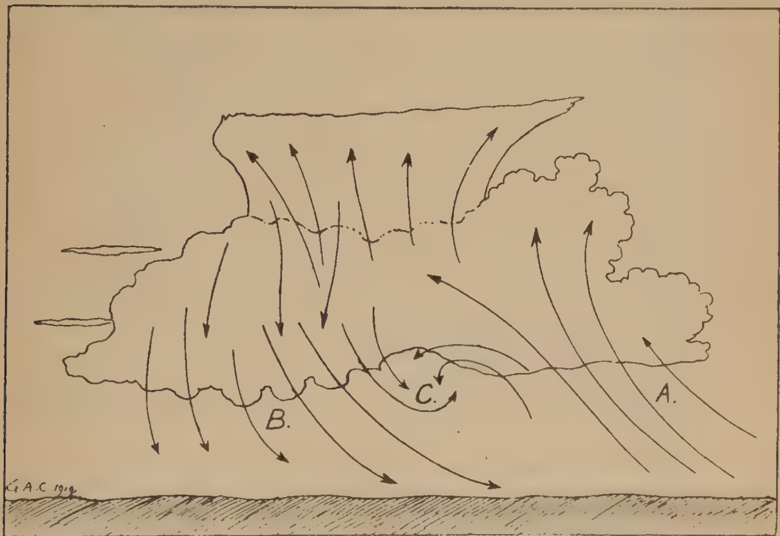


FIG. 13.—Vertical section showing structure of a thunder-cloud.

contact with the surface will become cooled, and the eddy-motion, which is caused by the friction met with by the wind in flowing over the earth's surface, will extend this cooling upward by mixing up the air, thus producing an inversion of the normal lapse-rate from the surface up to a height which depends upon the time and distance the current has been moving. Eddy-motion is most active during bright windy weather, and its action can easily be seen by observing how rapidly the smoke

from factory chimneys is tossed about and dispersed in the air by the atmospheric eddies. The shimmering seen along the horizons on land and sea is another illustration of their activity. Major G. I. Taylor, F.R.S., who has investigated eddy-motion, has explained the frequent and dense fogs met with off the Banks of Newfoundland as being due to the above cause.[1] He found that the warm air-current coming off the land to westward and also that coming from over the warm Gulf Stream water became cooled in their lower layers by contact with the water of the cold Arctic current from Baffin's Bay, and that the cooling was propagated upwards by the eddy-motion, whereupon the moisture contained in the warm air became condensed and formed a dense fog, which after all is but a cloud resting on the surface of the earth. An interesting development of this method of cloud-formation is often met with at Aberdeen during foggy weather in summer. An easterly wind leaving the shores of the Continent as a warm wind sometimes has its lower layers cooled by the water of the North Sea sufficiently to cause fog on our shores; or else the fog, which has been formed by the warm air lying for some time nearly stagnant over the North Sea, may drift westward under the influence of an easterly breeze. There is formed in such cases an inversion reaching upwards from the surface for a few hundred feet, the air gradually becoming warmer upwards for this distance before the normal falling-off of temperature with height occurs. When, however, this fog-laden air crosses the shore-line, the much warmer land at once commences to heat the surface layers again, and the

[1] G. I. Taylor, M.A., Report of S.S. "Scotia" to Board of Trade, 1914.

inversion begins to change back into the normal lapse, with the result that the fog evaporates near the surface and passes overhead as a low stratus cloud. Farther inland the inversion disappears altogether and the cloud dissipates also. Sir Napier Shaw[1] suggests eddy-motion as the cause of certain clouds in easterly and northerly winds of long "fetch," and some forms of cloud which are very common on the borders of anticyclones in easterly and south-easterly weather at Aberdeen can scarcely owe their existence to any other cause, for easterly currents in such types of weather maintain their easterly direction to comparatively great heights, while the clouds referred to are very low. There can therefore be no warm moist current from another direction to assist in their formation.

Clouds formed by this method are generally of strati-form or nimbus types, and are described in Chapter VI.

3. *Local or General Fall of Pressure* may, by causing expansion of the air, produce cloud if the air is near the point of saturation. It is possible that the cirrus and cirro-cumulus types may owe their formation, at least partly, to this cause. The great rapidity with which whole areas of sky may become covered with these clouds, and the gradual thinning away at the edges of the sheets, may be due to the flowing away of some superincumbent air; and condensation produced by the rarefaction would then take place in the damp areas. Cirrus clouds are formed just below the base of the stratosphere, where air-currents are probably flowing smoothly and horizontally, and this might account for their stream-like banded arrangement.

[1] Sir Napier Shaw, F.R.S., "Manual of Meteorology," Part IV, chap. v., 1919.

4. *The Mixing of Two Masses of Saturated Air of Different Temperatures.*—Clouds which may be produced by this method are likely to be only thin stratiform layers or films resembling haze. A cubic foot of air at a temperature of 64° F. contains, when saturated, 6·6 grains of water-vapour; the same volume at 50° F. contains 4·1 grains. If both volumes are mixed the temperature of the mixture becomes 57° F. and the water-vapour present will then be 5·35 grains per cubic foot. But air at 57° F. can hold only 5·2 grains per cubic foot, therefore the excess of 0·15 grain must condense as a cloud. But condensation will warm the air somewhat, so that only part of the excess will become cloud.

5. *Extensive Cloud-layers and the Effect of Radiation.*—Clouds that appear in widely extended sheets, sometimes covering vast areas, seem to be closely connected with the stratified conditions found in the atmosphere. Balloons with recording instruments attached to them have made many ascents into the free air, and their records have demonstrated that the atmosphere is really built up of a series of layers of air of widely differing temperatures and humidities, and also of varying velocities and directions of motion. Our knowledge of these conditions has been greatly added to by Captain C. K. M. Douglas, R.A.F., who, during the last year of the war, was attached to the Meteorological Section of the R.E. in France. Captain Douglas, in his aeroplane, which was fitted with thermometers and a camera, obtained a series of observations of the meteorological conditions in the neighbourhood of clouds, in addition to a large number of beautiful photographs of the clouds as seen from above. A few of these wonderful cloudscapes are shown in Plates 38 to 40. One of the most important

results was the confirmation of the intimate connection between strato-cumulus clouds and inversions of temperature, a fact which had previously been established by kite and balloon observations.[1] On passing through a layer of strato-cumulus Captain Douglas found that the temperature, which had been falling as he rose to the cloud level, often began to rise just above the clouds and the increase extended upwards for several hundred feet. Increases of temperature of from 1° F. to 10° F. were met with, and in some exceptional cases the values were even larger, an increase of as much as 15° F. having been recorded in 1000 feet of ascent. The cause of these inversions is still a somewhat debatable point; eddy-conductivity may, if vigorous, by mixing up the air, produce heating at the surface and cooling at the top of the layer in which it is operative, and at the same time will carry up moisture which will condense at the level where the air becomes saturated. But the fact that Captain Douglas frequently found the warmer layer above the clouds to be also much drier than the layers below seems to suggest that the inversion may sometimes be due to the slow descent of air, which is warmed in the process of descent. It is important to note that though *ascending* air may have its rate of cooling by expansion reduced to about 3° F. in 1000 feet owing to the access of heat liberated by condensation and rain-formation, *descending* air, on the other hand, must be warmed by compression at the adiabatic rate of $5\frac{1}{2}$° F. in 1000 feet and such air will therefore always be

[1] W. H. Dines, F.R.S., "The Vertical Temperature Distribution in the Atmosphere over England," "Phil. Trans. Roy. Soc.," Series A, Vol. 211, p. 253.

relatively dry.[1] The thickness of the layers of strato-cumulus is sometimes remarkable. Captain Douglas on frequent occasions has found them to be over 4000 feet thick.[2]

During quiet anticyclonic weather in winter-time, sheets of cloud of the stratus type, of from 500 to 2000 feet in thickness, often form at low levels. Mr. W. H. Dines is of the opinion that these cloud-sheets are most probably caused by the loss of heat due to radiation from the air layer in which they form.[3]

The elevation of a saturated layer or the reduction of its pressure will, by cooling, produce a cloud-sheet, and it is very probable that the widespread alto-stratus in cyclonic areas is formed in this manner. Captain Douglas has found this cloud generally to be composed of snow.

Another frequent cause of sheets of high cloud is the undercutting of warm damp currents in the upper atmosphere by colder ones from other directions, much the same process in fact as that which gives rise to the surface "line-squall". The warm air is forced upwards by the cooler current, the result being a wedge of warm moist air spreading above the cold air, and thinning out at its boundary into one of those clearly-defined sharp edges, sometimes hundreds of miles in length, that are so noteworthy a feature of the upper and intermediate

[1] W. H. Dines, F.R.S., loc. cit., "Phil. Trans. Roy. Soc.," Series A, Vol. 211, p. 253.

[2] For this and many more interesting details see the papers by Captain Douglas in the "Journal of the Scottish Meteorological Society," 1916-17-18, and also "Symon's Meteorological Magazine," December, 1919, and January, 1920.

[3] See "Manual of Meteorology," Part IV, p. 49, footnote.

cloud-layers (see Plates 10 B, 14 B). These sharp edges very frequently accompany the passage of the trough line of a depression, and are often revealed by the clearing away of the lower cloud at the moment of the passage of the trough line.

The beautifully waved structure seen in nearly all of the layer-types of clouds from cirrus downward to strato-cumulus is caused by the propagation upwards or downwards of the wave-motion that is produced by the flowing of air-currents of different velocities and directions over each other, and was first explained by Helmholtz. Exactly similar patterns are formed by water-currents rippling over sand, by the wind rippling the surfaces of the æolian sand-dunes, and also by the wind on the surface of drifted snow. It is not always that the wave-cloud occurs at the shearing plane between two currents, but as the wave-motion is propagated vertically it follows that wherever there may exist a layer near the point of saturation, any lifting of that layer will produce cooling and condensation. Consequently, where the crests of the waves occur, such a layer will be lifted and waves of cloud will be formed, while in the wave-hollows the layer will be depressed and the compression will prevent condensation, thus producing the intervals of blue sky between the cloud-bands. In addition to these easily visible waves there sometimes occur systems of very small ripples which can be seen only by telescopic aid. It is a well-known fact that if a flame—such as a candle flame—be held in the path of a ray of sunlight, the rising of the heated air can be rendered visible by letting the shadow of the candle fall upon a piece of white paper, or even by holding the candle between the eye and the sun. At Aberdeen a telescope with a dark-red glass

attached to the eyepiece has often been directed at the sun when bands of thin high cloud have been passing over the sun's disc, and on some occasions trains of tiny ripples lasting for only a second or two have been seen to form and disappear in rapid succession within the cloud-band. In these cases it has been the moving air itself that formed the ripples, and the air-current presented an appearance exactly like that of a swiftly flowing rippled current of water.

The lenticular cloud-banks are also due to a wave-motion. It has been mentioned that they appear in air-currents flowing across mountainous country, and therefore the obstruction offered by the mountain masses to the flow of the air will tend to elevate somewhat the air-layers above, when, if the latter are damp, condensation will occur at the points where the elevation takes place. Such a wave will be stationary or may move forward very slowly, and may set up similar waves in front of it; and the swiftly moving air will pass across this stationary wave-system, condensation occurring as it crosses the crest, and evaporation as it descends into the trough. The peculiarities of these clouds as described in Chapter III will thus be accounted for.

CHAPTER V.

CLOUD DISTRIBUTION, HEIGHTS, DIRECTIONS, VELOCITIES, AND FREQUENCIES.

Cloud Distribution.—The amount of cloud present in the sky varies very greatly with locality. Angot[1] states that in the same latitudes the amount of cloud is usually greater over the oceans than in the interior parts of the continents, while over desert areas the amount of cloud is negligible. Likewise there is more cloud on coasts which are subject to ocean winds, and less on those where the prevailing wind blows off-shore. Thus it is that Scotland, Ireland, and the north-westerly and central parts of England are more cloudy than is the south-eastern portion of England, the amount of cloud in our islands ranging from about 70 per cent. in the former districts to about 60 per cent. in the last named. The cloudiest part of the earth in the northern hemisphere is found in a belt stretching from the coast of Labrador round the south of Greenland, thence passing between Iceland and Scotland round the north of Norway below Spitzbergen. A similar belt crosses the north Pacific below Kamchatka and Alaska.

In our islands there is a greater amount of cloud during the winter half of the year, and the daily range

[1] A. Angot, "Traité élémentaire de météorologie," Book III, chap. ii., paragraph 68.

shows a maximum of cloud somewhere in the middle of the day, and a minimum very late at night. But in other parts of the world the annual variation in cloud amount differs greatly. For example, at high mountain stations the maximum of cloud occurs in summer and the minimum in winter, because the clouds being relatively lower in winter are then found chiefly *below* the level of the station. Then again, stations which experience a wet summer season, as do those on the west coast of India, have a decided maximum of cloud in summer.

Cloud Heights.—In Chapter II there were given the average heights of each cloud type. But, as might be expected, the average height of any particular type of cloud depends upon the latitude; a greater height is found in the equatorial regions and a lesser one in polar latitudes. This fact was well brought out by the international cloud observations made throughout the world in the years 1896-97. There was also proved to exist an annual variation in heights: in summer the clouds are higher than in winter, the actual curves showing this annual height-variation have been given by Bigelow.[1] As a rule the maximum height occurs in summer, and the minimum in winter or early spring.

Directions of Cloud-motion.—In our latitudes in the northern hemisphere the prevailing surface winds are from the south-west, but higher up in the atmosphere the winds become steadily more westerly. That this is a fact has been demonstrated from the results of pilot balloon ascents made at the Meteorological Office obser-

[1] Bigelow, "Report on International Cloud Observations," 1900. "United States Weather Bureau," quoted in McAdie's "Principles of Aërography," 1917.

vatories and also at Petersfield by Captain Cave.[1] It is also borne out by the directions from which the clouds move. An analysis of the directions of cloud-motion from observations made at Aberdeen with the Fineman nephoscope is given in the supplement to the "Geophysical Journal"[2] for 1916. The observations cover a period of five years from 1912 to 1916, and the results are shown in the vector diagrams in Fig. 14, where eight types of cloud are represented. The two other types, nimbus and stratus, are not amenable to measurement. But in the types analysed it is perfectly obvious that by far the greatest proportion of the clouds come from some westerly point, while the paucity of easterly directions is remarkable. Strato-cumulus shows the least bias, and is somewhat resembled in this respect by alto-cumulus, and rather less so by cirro-cumulus. Cirro-stratus and alto-stratus do not convey an altogether correct impression, because both these types occur very frequently in front of a depression and should therefore show a considerable grouping between south and south-west in addition to the westerly maximum. But when in front of a low-pressure area, both these types are very uniform and do not give sufficient detail to enable measurements to be made of their motion, except on rare occasions; the diagrams given are the results of measurements chiefly of the types which show a reticulated structure, and which are usually found in westerly weather.

Most of the cloud-types exhibit some inherent peculi-

[1] C. J. P. Cave, M.A., "The Structure of the Atmosphere in Clear Weather," 1912.

[2] "Geophysical Journal," 1916. Meteorological Office, 227 (d), "Annual Supplement," p. 80. The observations and vector diagrams are herein given in much greater detail.

arity; thus cumulus and cumulo-nimbus are found chiefly in the north-westerly quadrant, the cumulo-nimbus hav-

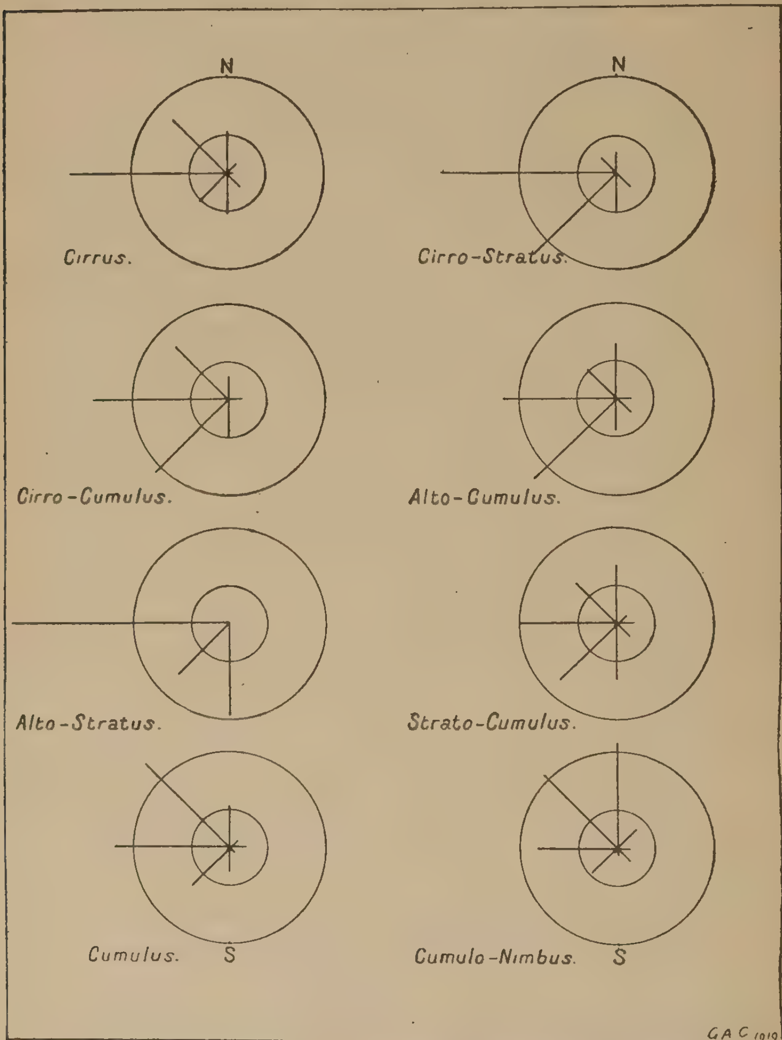


FIG. 14.—Percentage frequency of directions of cloud-motion at Aberdeen. The outer circle indicates 25 %$_0$ of total number of observations; the inner one indicates 10 %$_0$. The straight lines show the percentage of observations of cloud from each direction.

ing a more northerly bias than the cumulus. Had it been possible to measure nimbus and stratus, the former would have shown a strong maximum between south-east and south-west, while the latter would have been distributed mainly between south-east and north-east.

Cirrus shows a decided maximum from the westward, but it is noteworthy that all the cirrus types are on a few occasions found to move from some easterly point, so that easterly winds may at times reach up almost to the base of the stratosphere.

The sequel to these distributions is given in Chapter VI.

Using the international cloud observations as a working basis, Hildebrandsson and Teisserenc de Bort[1] have formulated a most suggestive and interesting explanation of the general atmospheric circulation on the earth. In equatorial regions the cirrus clouds showed an *easterly* current of high velocity in the upper air.

Velocities of the Clouds.—The velocities of the clouds were also measured at Aberdeen simultaneously with their directions, and the results obtained demonstrated that in general the apparent velocities were greater in winter than in summer, very markedly so in the case of the "convection" type of clouds, cumulus and cumulo-nimbus. This must be due partly to the stronger winds in winter, but partly also to the lower altitude of the clouds at that time of year. The cloud-velocities measured were their *angular* velocities, and these would have to be modified according to the actual heights of the clouds in order to obtain their actual velocities. If the average angular velocities as found by observation are

[1] Hildebrandsson and Teisserenc de Bort: "Les bases de la météorologie dynamique," chapter iv, 1903.

treated in this manner, using for the average cloud-heights those that are given in the International Classification, then the following average actual velocities in miles per hour are obtained: cirrus 60, cirro-stratus 60, cirro-cumulus 45, alto-cumulus 30, alto-stratus 35, strato-cumulus 22, cumulo-nimbus (central mass of cloud) 35, and cumulus 31. Some of the individual velocities obtained for cirrus in a westerly current were very high, for even assuming the height of the cloud to have been only 23,000 feet instead of the 30,000 feet given as the average, the velocities not infrequently reached 100 or 130 miles per hour.

Frequencies of the Cloud-types.—Though any particular type of cloud may occur at any time, yet there exists some slight periodicity in the appearance of certain types, notably in the cases of the cumulus and cumulo-nimbus, which show a seasonal range as markedly as they do a diurnal one. The analysis that has just been quoted, together with another one which deals exclusively with the frequency of cloud-type,[1] both tend to show that at Aberdeen these two cloud-types are more frequent at the equinoxes than in midsummer and have an absolute maximum in April. On the other hand, at Epsom in the South of England, an analysis made by S. C. Russell[2] shows a definite maximum for these types in midsummer. Both the Aberdeen and Epsom analyses agree in showing strato-cumulus to be more frequent in winter than in summer, but Epsom has the

[1] "An Analysis of Cloud Distribution at Aberdeen, 1916-1918," by G. A. Clarke. M.O. Professional Notes, No. 9, 1920.

[2] Spencer C. Russell, "Results of Monthly and Hourly Cloud-form Frequencies at Epsom, 1903-1910," "Q.J.R. Met. Soc.," October, 1913.

maximum for the cirrus varieties during the summer while Aberdeen records a late autumn to winter maximum for them. The existence of such differences between two stations almost at the two extremities of Great Britain demonstrates that the cloud conditions vary very greatly with locality.

This fact is likely to have a considerable bearing upon aerial navigation, for, in the event of transport by

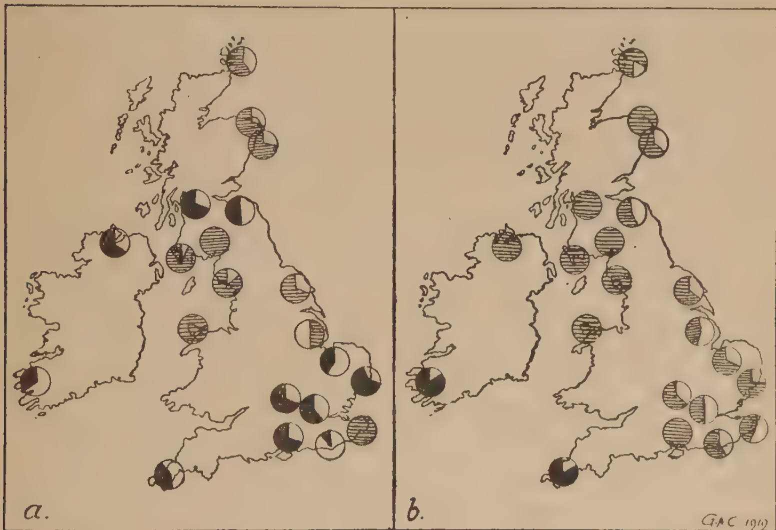


FIG. 15.—Distribution of cloud at meteorological stations.

air assuming any considerable dimensions, it will become necessary for the cloud conditions at all stations to be known. Recently the Meteorological Office in its "Upper Air Supplement to the Daily Weather Report" has been giving maps indicating the cloud at a number of stations. Fig. 15 shows a modification of these maps, two examples being given showing different conditions. In (*a*) there is shown a case where a good deal of high cloud (7000 feet and upwards) is present, and only a

small quantity of low cloud (below 7000 feet) though in the south-east of England it is of unfavourable type, that is to say, the cloud is either of the convectional order (cumulus or cumulo-nimbus), which makes the air very "bumpy," or there is fog present or else rain is falling and destroying visibility. In (*b*) there is much low cloud, but little convectional cloud or rain is present. In the maps the proportion of the circle covered with each shading shows the proportion of that particular cloud-type visible at each station. The solid black shading indicates convectional cloud, rain, or fog, the hatched shading shows low cloud (below 7000 feet), and the unshaded portions indicate either clear sky or high cloud (above 7000 feet).

CHAPTER VI.

THE ASSOCIATION OF CLOUD WITH WEATHER TYPE.

FROM the earliest times it has been customary for observers of the weather to associate certain cloud forms with certain kinds of weather, and by patient observation and correlation much knowledge has thus been obtained which is of value. It has been established that certain clouds or combinations of cloud-types are liable to recur in similar weather conditions; of these the general sequence of cloud in a cyclonic depression is the most familiar. But even the same clouds do not always mean the same weather in all localities. Angot, in his treatise on meteorology[1] mentions that cirro-cumulus in our islands is usually a good sign, while in Italy it portends the reverse; and that cirrus, when light and motionless, accompanies very fine weather, but if seen in swiftly moving bands is generally the forerunner of a storm. If, however, weather-type, as determined by the pressure distribution, is taken into consideration instead of the actual weather, it is found that certain cloud-forms are more prevalent than others according to the weather-type in question. In the diagrams which accompany this chapter there are shown the British Isles and some neighbouring parts of the continent. Over each map there is drawn a certain arrangement of lines indicating where barometric pressure is the same; these

[1] Loc. cit., Book B, chapter i, par. 111.

are the "isobars" that have been referred to in Chapter IV, and according to the direction in which they lie, and to the relative positions of the high and low pressures, the prevailing winds can be deduced from them. It is convenient to refer to the wind as a method of indicating the weather-type. Thus an arrangement of isobars running north and south with high pressure to the west and low to the east, will have in general a northerly wind blowing across our islands, and can be termed "northerly" weather. In the maps the arrow (or arrows) indicate the direction of the wind, and the numbers at the top of the isobars are conventional readings of the barometer.

The following details of cloud likely to be found in each weather-type are from observations at Aberdeen only and may therefore to some extent be influenced by locality.

South-easterly Type.—High pressure lying generally over Scandinavia and low pressure to the south-west of Ireland. Wind varying between S.E. and E. Cloud is almost always of the stratus type, sometimes complete, when it may degenerate into a nimbus pall with light drizzle, at other times broken into cumuliform masses. It is often very persistent. When moving from about east, these masses very strongly resemble sheets of strato-cumulus, and are apparently the clouds referred to by Sir Napier Shaw[1] as due to eddy conductivity. They are extremely difficult to classify satisfactorily; possibly a name like "eddy-cumulus" might best describe them. The accompanying weather is rather variable but generally cloudy to dull with mist and drizzling rain.

[1] See Chapter IV, page 69.

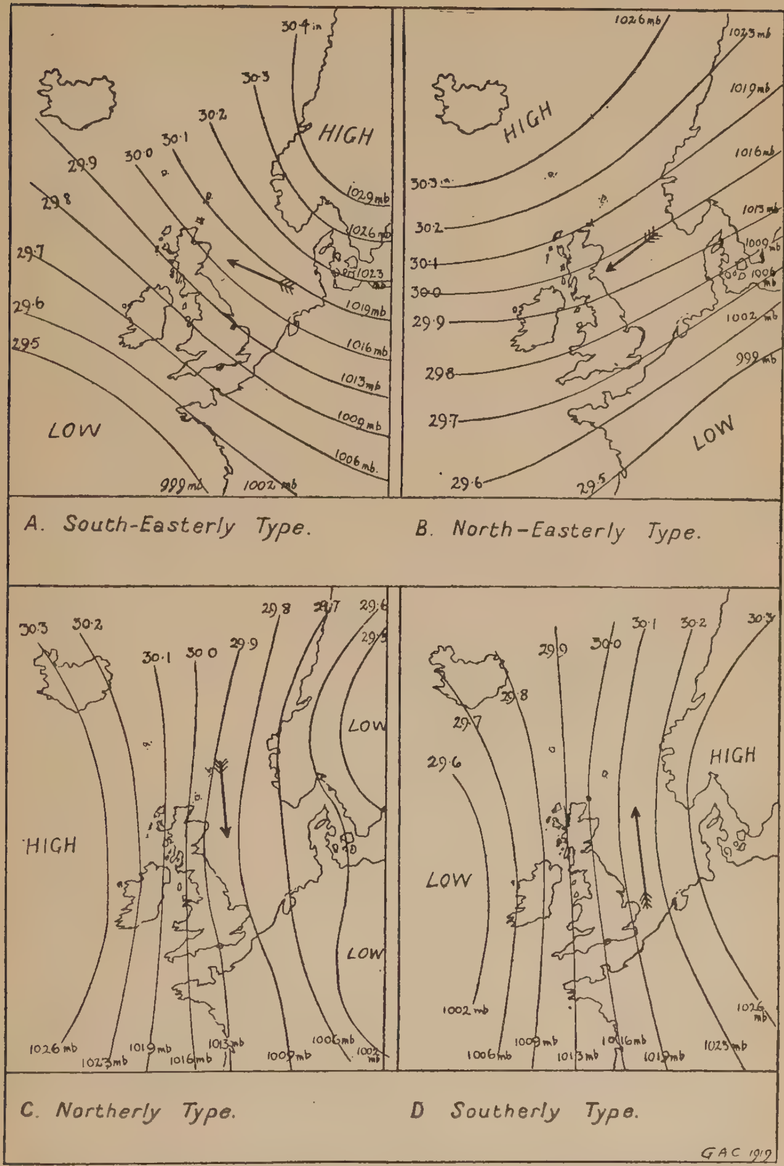


FIG. 16.—Examples of weather-types. Isobars marked in inches and millibars.

North-easterly Type.—High pressure to N.W. of Scotland, low over eastern France. Wind varying between E. and N.N.E. The cloud, when the wind is more easterly, is of cumuliform stratus type similar to that mentioned above, but as the wind backs more to the northward this gradually gives place to rather larger masses, exactly like the ordinary cumulus in appearance, or sometimes resembling small cumulo-nimbus, when very slight showers may fall from them. Above them is a layer, more or less complete, of normal strato-cumulus, into which the summits of the lower cumulus and cumulo-nimbus at times reach. The accompanying weather is mostly fair, and visibility as a rule is very good.

Northerly Type.—A large anticyclone to the west of Britain and either a single or multiple low to the east of the North Sea. Wind from N.N.E. to N.W. Characterised almost exclusively by small to moderate-sized cumulo-nimbus clouds, of which the "anvil" portion usually forms the major part; the clouds move from a direction somewhat more easterly than that of the surface wind, especially the upper "anvil" part, which usually develops into a layer of small strato-cumulus or alto-cumulus as the wind dies down. Weather is very squally and cold; with very frequent showers of rain, hail, sleet or snow.

Southerly Type.—The isobaric conditions are exactly the reverse of the above. Wind is between S.S.E. and S.S.W. This type shows a double cloud character. If the British Isles come more under the influence of the anticyclone the cloud is chiefly a low broken stratus, sometimes with strato-cumulus above it, but under the influence of the low pressure the dominant types are

cirro-stratus and alto-stratus with "scud" stratus below. Nimbus may follow if the low pressure advances farther over our islands but the sequence of cloud in this case is dealt with under *cyclonic weather*. The usual weather in this southerly type is dull, gloomy, misty and raw, generally with some rain.

South-westerly Type.—The isobars often stretch from the Azores to Norway straight across our islands, or else are curved as indicated in the figure. Pressure is high over the continent, low out on the Atlantic, and the wind blows from some point between S.S.W. and W.S.W. The clouds comprise all the varieties of upper and intermediate clouds from cirrus and cirro-cumulus to alto-cumulus and strato-cumulus. Occasionally some slight cumulus and broken stratus may also be present. At Aberdeen all the intermediate and higher clouds above-mentioned appear grouped in lenticular masses, which is a local characteristic, as was described in the previous Chapters III and IV, and the weather found at Aberdeen under these conditions is very warm and squally, probably also a local modification of the general fine dry weather of the anticyclone. Farther to the west the weather may come under the influence of the Atlantic low pressure and there may then be more low stratus and nimbus cloud.

Westerly Type.—High pressure lies to the south, over the Bay of Biscay and Spain, and the isobars run from west to east across our islands. Low pressure is found to the north between Iceland and Norway. Wind at the surface blows from between W.S.W. and W.N.W. The chief characteristic clouds of this weather-type are finely formed bands of cirrus and high cirro-cumulus, changing occasionally into sheets of cirro-stratus and

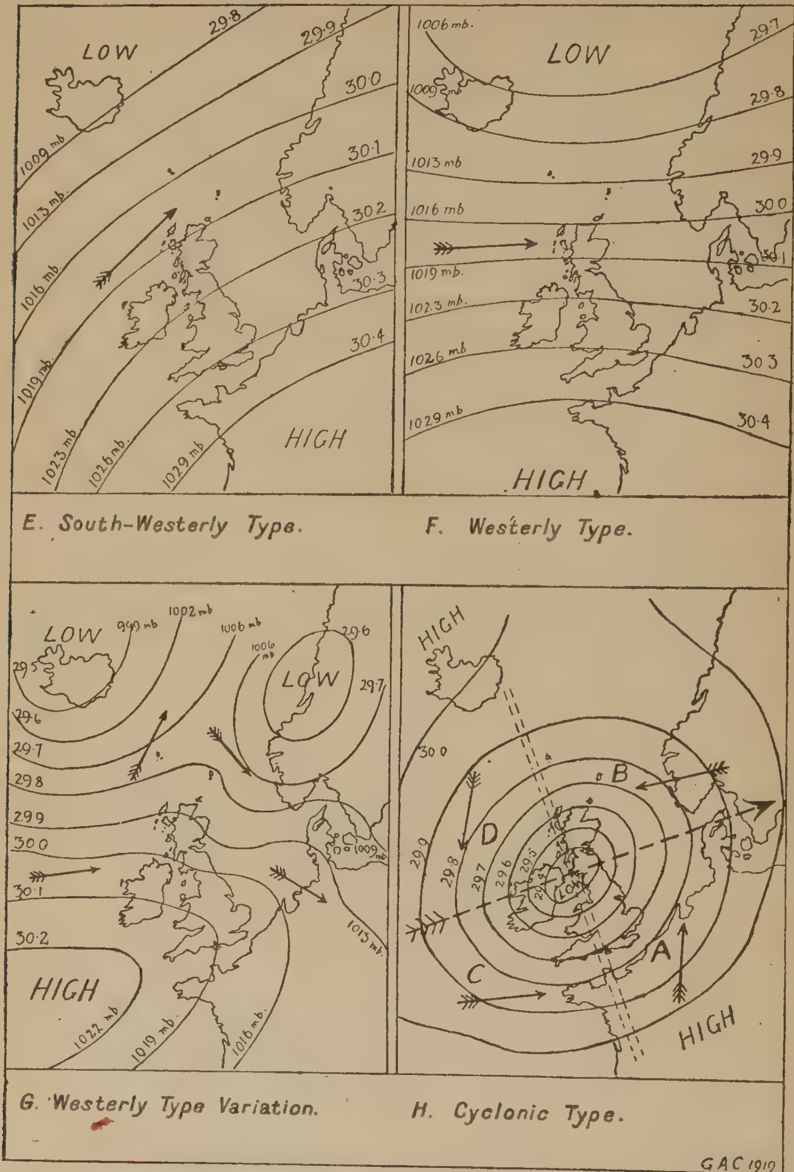


FIG. 17.—Examples of weather-types. Isobars marked in inches and millibars.

alto-stratus. Sometimes they are accompanied by lenticular clouds of the south-westerly type, and there may also be some strato-cumulus present, but only very slight quantities of cumulus are seen. The weather is usually fair.

The next type (Fig. 17 (g)) is a variant of the westerly type, where the high pressure is situated out on the Atlantic to the south-west of our islands, and spreads across them in a projecting shoulder. A succession of depressions is passing in an E.S.E. direction across the northern part of Great Britain towards the continent, and the shoulder of the high thus becomes a region of frequent surges of low pressure. It is a very common distribution, and has been mentioned here because it seems to be a region where the cloud is chiefly of the strato-cumulus type. A fair amount of cumulus is also present, and in this respect the region resembles the rear part of a cyclone.

Cyclonic Type.—Owing to its comparatively rapid rate of travel, this type shows a sequence of cloud-forms that has become very familiar to most people. In the diagram the large dotted arrow shows the path and direction of the movement of the depression, and the small solid arrows the various winds found in the different sectors of the cyclone. The dotted double line represents the "trough" of the depression—the line along which the pressure commences to rise again. Considerably in front of the cyclone, sometimes even before pressure has begun to fall, there will be seen banded cirrus, moving from the S.S.W.; this will gradually close up into cirro-stratus, which in turn will thicken into alto-stratus as condensation increases. Then as the mercury falls at an increasing rate the nimbus cloud with rain

follows. In the right front sector (A) the nimbus is usually dense and ragged with "flying scud" below it; in the left front sector (B) it is more uniform in appearance and the rain is usually less heavy but very persistent. Occasionally the rain continues to fall for a short time after the pressure has begun to rise, but at other times the passage of the trough line over a station is accompanied by the cessation of the rain and the commencement of the clearing of the nimbus cloud. When this takes place cirro-stratus or alto-stratus may still be seen above the broken lower cloud, but this high cloud also disappears before long, and in the rear of the disturbance the cloud-forms are usually strato-cumulus, cumulus, and fracto-cumulus in the right rear sector (C) and strato-cumulus with fracto-cumulus and small cumulo-nimbus in the left rear (D).

In the cases where the cyclone is elongated into what is known as a "V" shaped depression the passage of the trough of the "V" is often accompanied by conditions similar to those of a line-squall, and the cloud in this case is very thick and heavily mammillated, and of the cumulo-nimbus character. The "clearing squall" often shows an upper cloud-sheet with a straight edge, still moving from the south-westward, though the surface wind has become north-westerly.

The nimbus cloud in small secondary depressions is often mixed with the cumulo-nimbus type and accompanied by thunderstorms.

The foregoing are, of course, simply generalisations upon the distributions of cloud-types. Weather-type is perpetually in a state of flux, and therefore the cloud-character is one of constant mutation. Therein lies its

greatest interest, and of the problems it presents to us many of the most important still remain unsolved. Those who would become acquainted with these problems are recommended to turn to the pages of Sir Napier Shaw's book "Forecasting Weather".

SECTION II

NOTES ON PLATES OF PHOTOGRAPHS OF CLOUDS.

In the following plates the clouds have been so arranged that the highest varieties come first, and all the other types follow in the order of their heights.

Opposite each illustration there is given in italics the correct classification for each cloud according to the international nomenclature; and the classification is followed by a detailed description giving the salient features of each cloud picture. It is hoped that by these means observers may find a ready guide to the classification of such clouds as they may from time to time observe.

For the benefit of those to whom cloud photographs may not be quite familiar, and who may therefore experience some slight difficulty in correctly translating them, it may be mentioned that the blue of the actual sky appears as varying shades of grey to black in the pictures according to the methods employed in taking the photographs. In all the pictures of cirrus, cirro-stratus, cirro-cumulus, and false cirrus, as well as in some thin varieties of alto-cumulus, the cloud appears as *white* on a *black* sky. In the case of the heavier lower clouds, and of the lenticular cloud-banks, the clouds show definite shadows, which appear sometimes darker than the sky tone, and sometimes lighter, but all the examples shown have been chosen with a view to eliminate any possible confusion of cloud-shadow with sky. Alto-stratus and stratus being uniform cloud-sheets have no blue sky visible, and therefore appear in tones of grey as they do in nature.

PLATE 5.

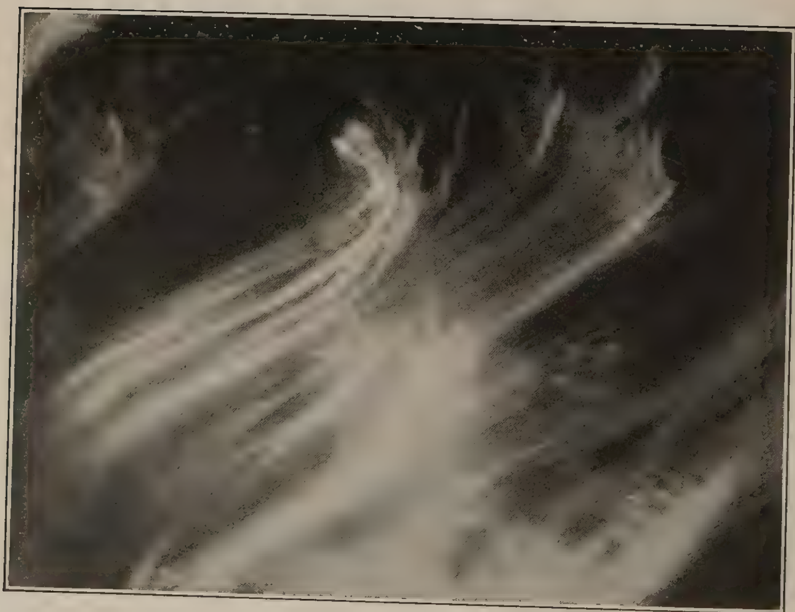
5A. *Cirrus.* Tufts of cirrus with extremely delicate thread-like continuations. The cirrus is moving in the same direction as that in which the lines are lying; the tufts preceding, the tails following.

5B. *Cirrus.* Photograph taken a few minutes later of the same bands of cirrus as shown in the above view. The tails have become much denser and longer, but, though perspective has altered the relative positions of the tufts, yet there is no difficulty in recognising the same tufts in both photographs.

A

B

A



B

PLATE 6.

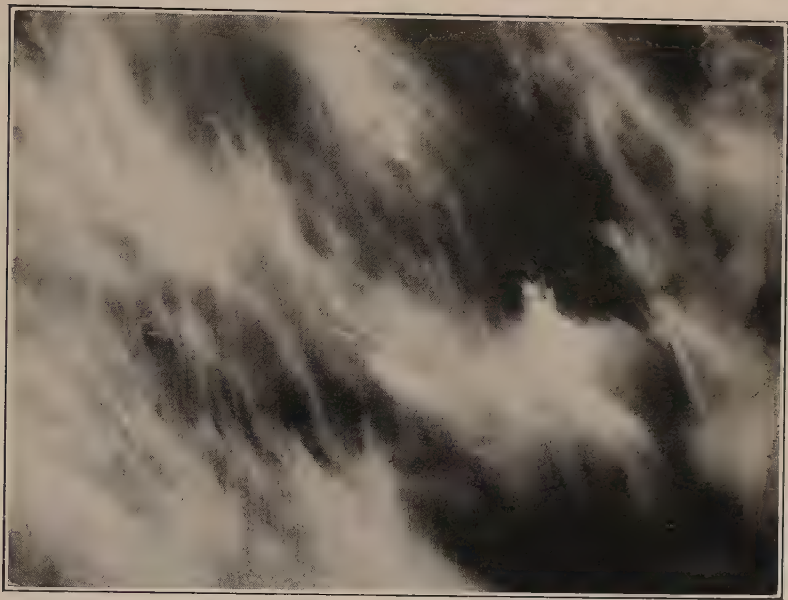
6A. *Cirrus.* An extremely fine example of long threads of cirrus, ending in some cases in dense tufts. This formed part of a long band of cloud, and the threads were lying *transversely* across the band.

6B. *Cirrus.* Extensive curved threads, forming part of a huge plume of cirrus. The ends of the threads show the familiar tufts, though not so markedly as in the foregoing case.

PLATE 7.

7A. *Cirrus*. Very dense masses of cirrus which give evidence of considerable vertical thickness. A type which showed very rapid changes of form and eventually became cirro-cumulus. Thread structure is very slight and ill-defined.

7B. *Cirrus*. Isolated, rather heavy threads of cirrus which show at their lower extremities a tendency to break up into faint flakes. This process continued until the whole band became ordinary cirro-cumulus.



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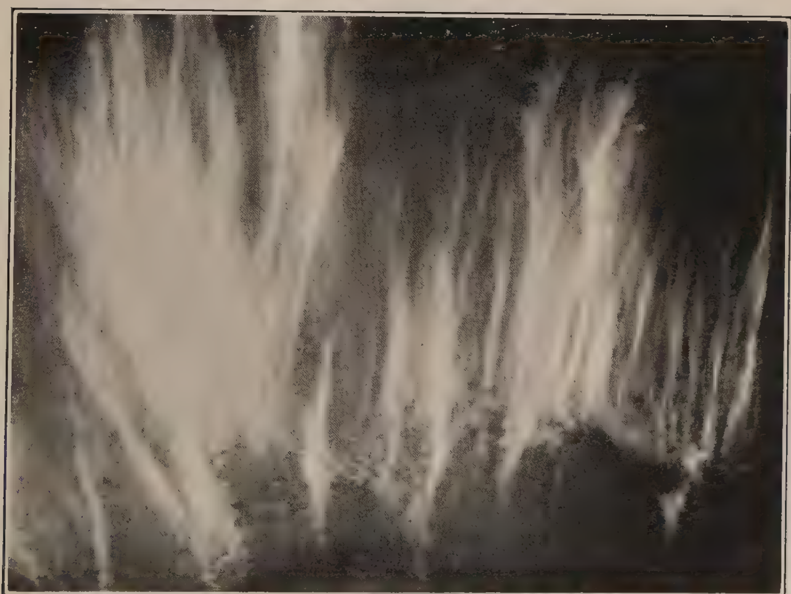

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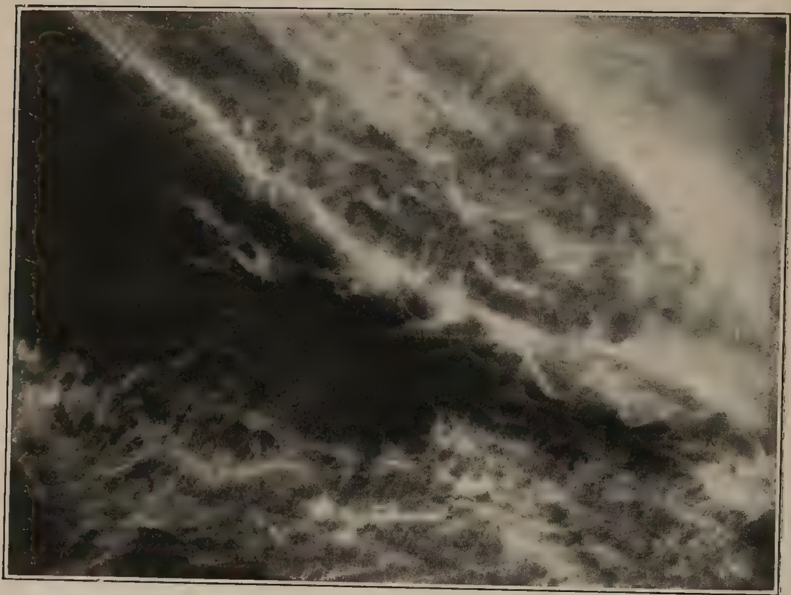

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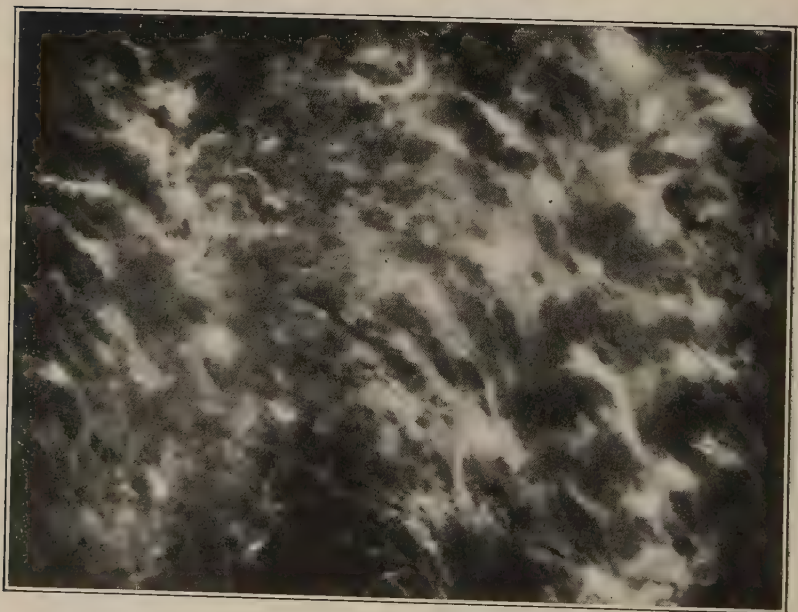


B

PLATE 8.

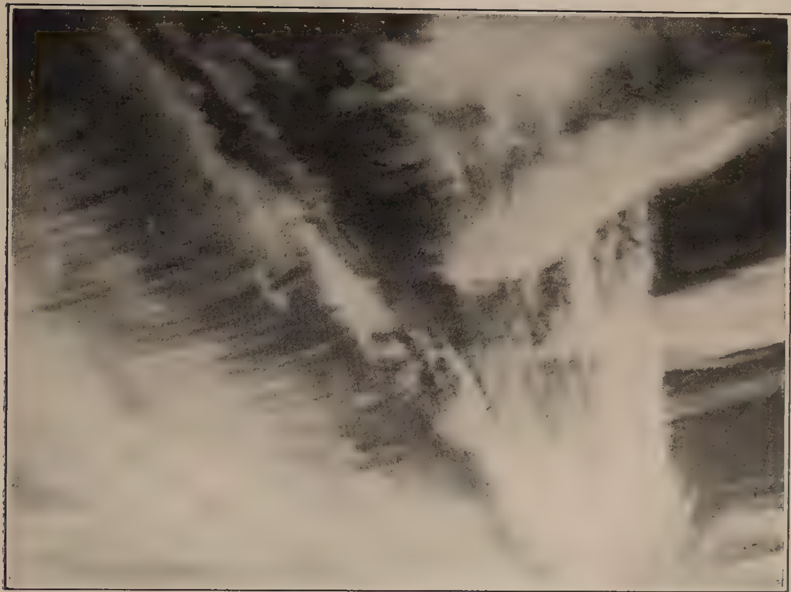
8A. *Cirrus.* Long and very sharply defined threads along which there occur nuclei from which other threads spread outwards more or less transversely to the main threads. This form often develops into the wave-like arrangement shown in Plate 12B.

8B. *Cirrus.* Detail of a portion of a long cirrus band. A rather unusual variety of the tufted forms. Throughout the length of the band there was considerable variation; in some portions the filaments were curved but delicate in structure, and in others the cirro-macula or "speckle-cloud" form was developed.

PLATE 9.

9A. *Cirrus.* A very interesting case where cirrus cloud is present at two levels. The higher of the two is represented by the small patches lying nearly horizontally at the right-hand side of the picture. The lower cirrus is represented by the converging bands running from top to bottom of the picture. These latter bands show two different characters, the right-hand one being inclined to the "speckle-cloud" type while that on the extreme left consists of very delicate transverse threads. Both cloud layers were moving away from the observer towards the direction shown by the convergence of the bands. The lower cirrus cloud was moving apparently about half as fast again as the upper layer.

9B. *Cirrus.* The same cloud as the above, but photographed some ten minutes later. The upper cirrus layer is here shown in greater extent, while the lower layer is reduced to a single band which exhibits well-marked wave-motion across its length. The change in the angle at which the band is lying is, of course, the effect of perspective; the band lay to the right of those shown in A above, and converged to the same vanishing-point.



A

B

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B

PLATE 10.

10A. *Cirro-stratus.* Type formed by the coalescence of a multitude of fine cirrus threads. Sheets of this type are found spreading out in advance of a depression. Note the increase in the density of the cloud at the left of the picture.

10B. *Cirro-stratus.* Part of a widely spread sheet of very dense cirro-stratus some twenty thousand feet or more above the small cumulus clouds along the horizon. The straight edge, which lay to the westward, was very remarkable, inasmuch as it persisted for at least twelve hours, the cloud moving in the direction indicated by the line of the edge, that is, from left to right, so that if the cloud had been moving even at the comparatively moderate velocity of 40 miles an hour, the edge must have been at least 500 miles in length. As time went on the cloud grew denser, finally becoming alto-stratus, and early next day a fierce blizzard broke over Aberdeen and the north of Scotland generally.

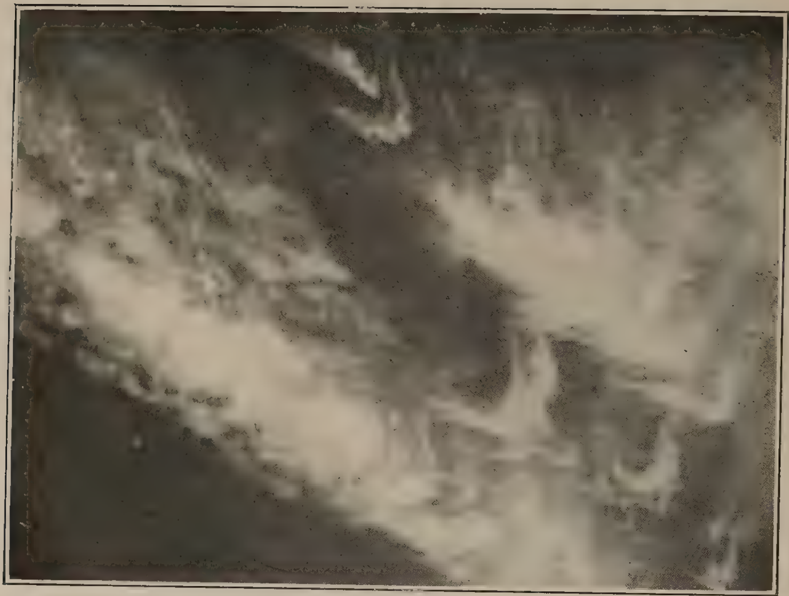
PLATE 11.

11A. *Cirro-stratus.* Actually a very fine example of cirro-nebula, the cloud being so delicate as to be practically invisible. The sun is hidden by the dark mass of strato-cumulus at the bottom of the picture, and the ice-crystals, of which the cirro-nebula is composed, are producing in the cloud the bright arch of light which is part of a very fine solar halo. The angle of view of the camera-lens was insufficient to enable the whole halo to be included in the photograph.

11B. *Cirro-stratus.* Broad bands of cirro-stratus edged with filaments of cirrus, and having above them a narrower band showing the rippled structure characteristic of cirro-cumulus. A rather dense variety of cirro-stratus, showing no thread-structure except at the upper edge.

A

B



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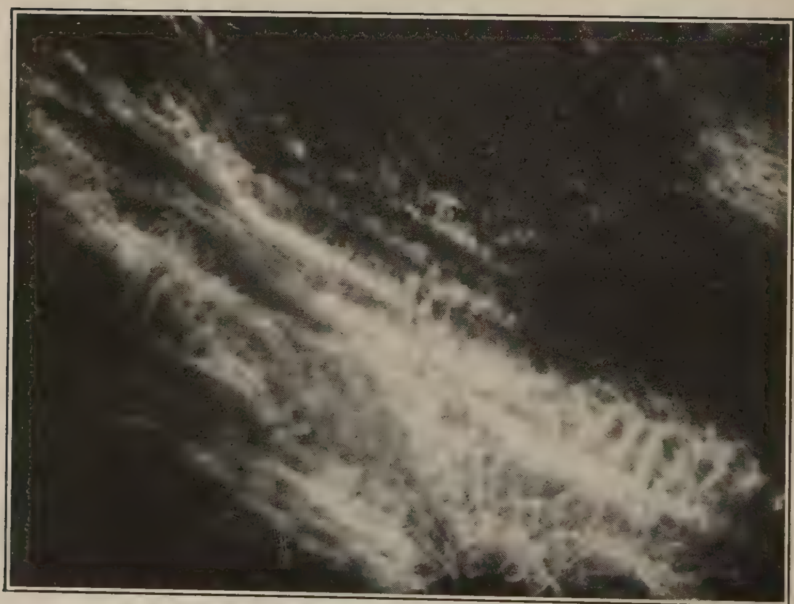


B

PLATE 12.

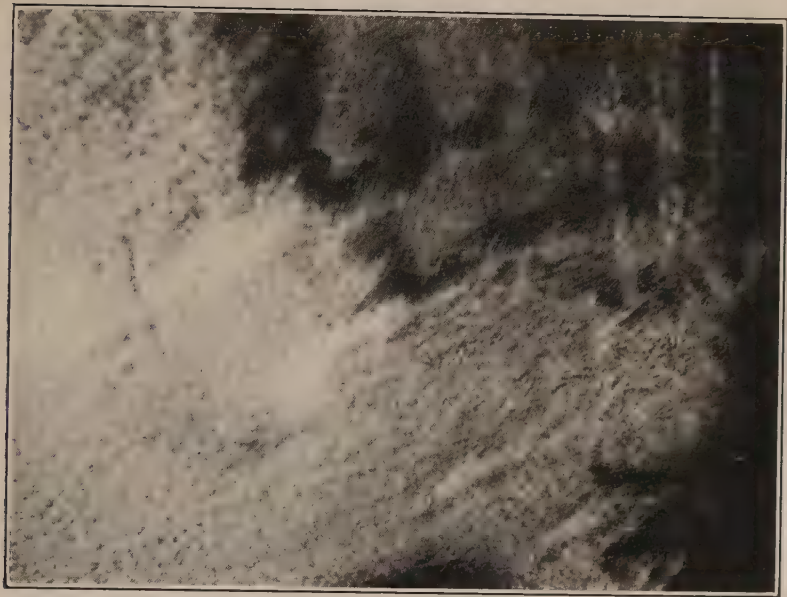
12A. *Cirrus.* The form of cloud that shows an intermediate condition between the cirrus and cirro-cumulus types. Threads and filaments are mixed up with small globular masses that strongly resemble little balls of cotton-wool and are intensely white. This form is often found arranged in long bands during westerly weather.

12B. *Cirrus.* The waved form that usually develops from cirrus of the type shown in Plate 8A. It is very evanescent, and has been called "change cirrus" by Clayden because it is in a state of continual flux between the cirrus thread form and the cirro-cumulus type. When extensive, it is probably the most beautiful variety of cirrus.

PLATE 13.

13A. *Cirro-cumulus.* An example of the variety termed "speckle-cloud"; the globules of cloud are excessively minute toward the edges of the sheet, where they become mixed with very delicate threads of cirrus.

13B. *Cirro-cumulus.* Part of a long band of small cirro-cumulus, fringed with a line of cirrus plumes. Both types belonged to the same system, the gradation from the one to the other being visible in various places along the edge of the cirro-cumulus. In a short time the cirrus became transformed into cirro-cumulus.



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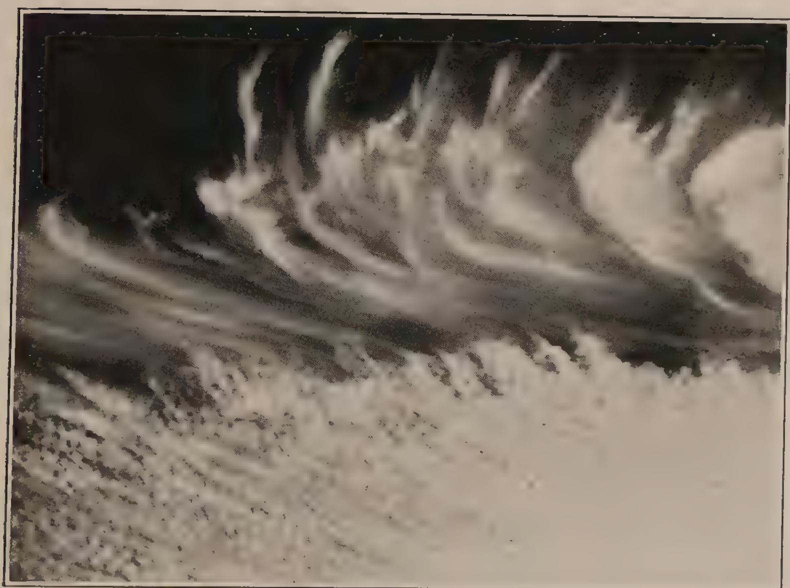

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PLATE 14.

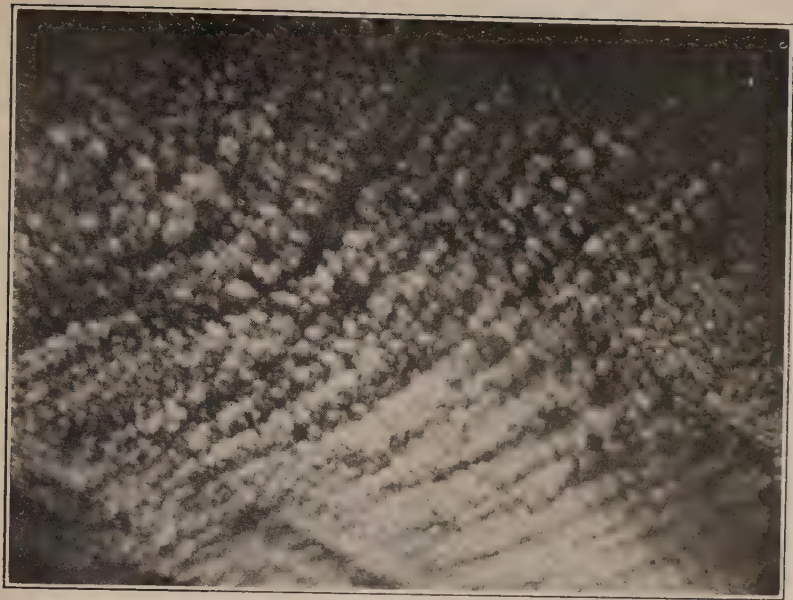
14A. *Cirro-cumulus.* Intensely white high cloud in radiating bands. At the upper left-hand corner it will be seen that the cloud is opening up into the familiar globular masses of cirro-cumulus. The height of these bands was probably about 20,000 feet, while the broken cumulus below was not more than 5000 feet high.

14B. *Cirro-cumulus.* The same bands mentioned above as they appeared some time later and in a different part of the sky, which accounts for their different apparent orientation. The character of cirro-cumulus is now well-developed, and wave-motion can be seen in the bands both longitudinally and transversely. These bands were not less than 250 miles in length.

PLATE 15.

15A. *Cirro-cumulus.* Part of a sheet of fine globular cirro-cumulus which exhibits double undulation, the transverse system being rather irregular. This example formed very rapidly from a previously uniform cloud-sheet.

15B. *Cirro-cumulus.* The waved type of cirro-cumulus, the cloudlets being formed by a single wave-system. Such clearly defined waves are usually very transient, but this example was of fairly considerable duration, the cloudlets gradually evaporating at the upper edge of the sheet. Some very dark strato-cumulus occupies the lower part of the picture.



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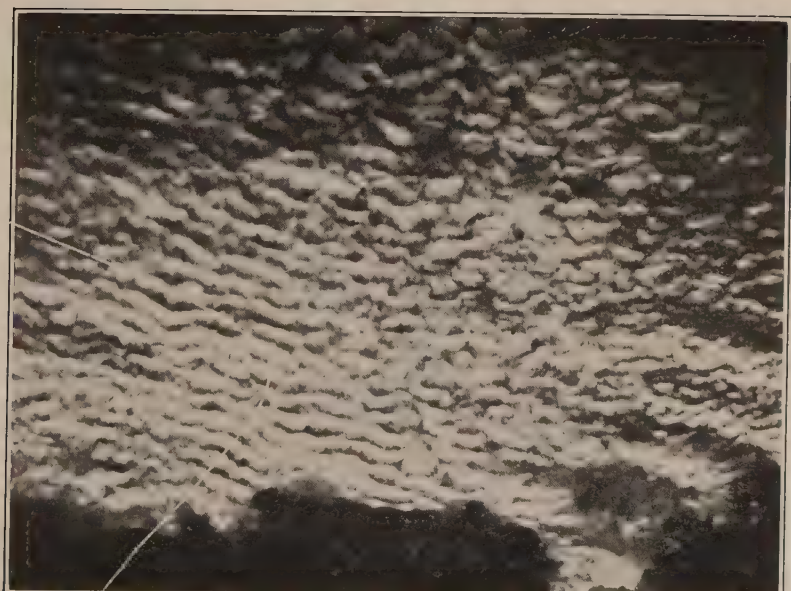

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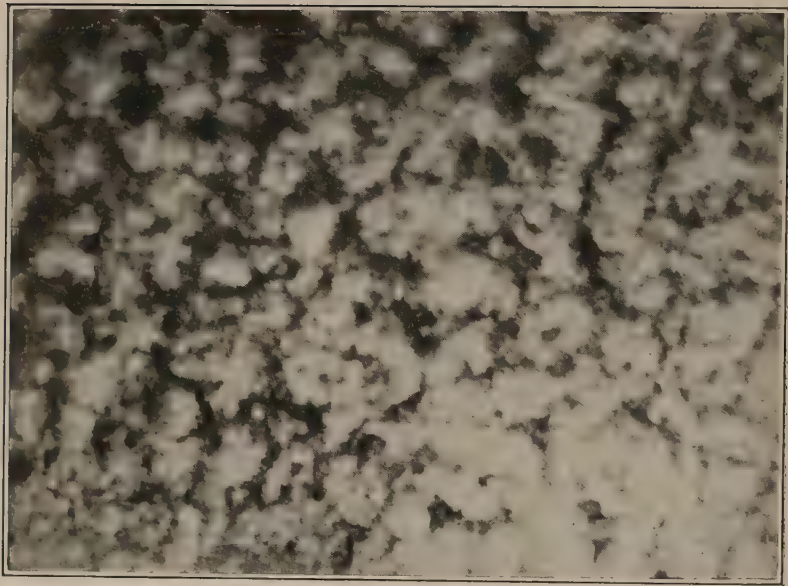

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PLATE 16.

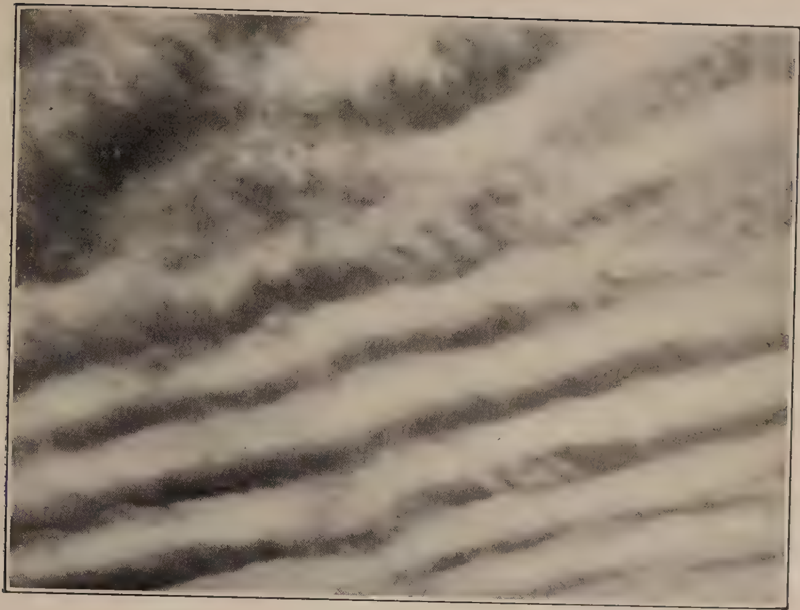
16A. *Cirro-cumulus.* A very unusual variety wherein the cloudlets are massed into small irregular rings with an open centre, thus giving the grouped arrangement a "rosette" appearance. This arrangement may be seen occasionally in most globular forms of cirro-cumulus, but seldom so well-marked as in this case. The cirro-cumulus is also of a heavier type than usual.

16B. *Cirro-cumulus.* Very sharply defined parallel bands of cirro-cumulus, showing regular cross-striation in the two central bands, while the widest band has a flaked structure. In this case the bands were of no great length, and lasted for only about an hour; they were also quite local, the remainder of the sky being free from cloud of that type, and showing only a few detached cumulus clouds, some of which may be seen in the lower half of the picture.

PLATE 17.

17A. *Alto-cumulus.* Long waves of alto-cumulus which do not exhibit any shadows on account of the thinness of the cloud. The wave-system was well marked only in this portion of the cloud-layer, the rest being more diffuse and irregular, as may be seen near the top of the photograph.

17B. *Alto-cumulus.* Another example of cloudlets without shadows; in this case the waves are sinuous instead of straight. The thinness of the cloud-layer is very obvious, especially on the left-hand side of the picture, but this was the case only at the edge of the layer, at the point where the photograph was taken. Farther to the right, the cloudlets were much denser and showed the normal shadowed appearance.



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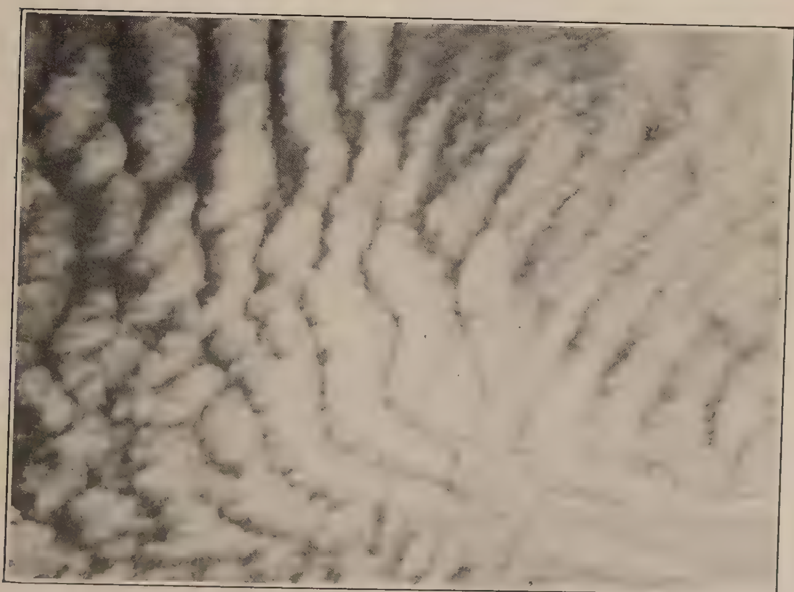

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PLATE 18.

18A. *Alto-cumulus.* A finely formed globular variety, the cloudlets of which are progressively smaller towards the lower edge of the picture. This was actually the case, and is not entirely the usual effect of perspective. The shadows are well shown, and the very globular form is an indication of the cloud's kinship to the "turret-cloud" form shown in Plate 24A.

18B. *Alto-cumulus.* Arranged in flakes and small masses that have a flattened appearance. This is a very common form of alto-cumulus in the neighbourhood of Aberdeen, being much more frequently seen than the waved types, and it is also frequently seen at the advancing edge of a widespread sheet of heavier strato-cumulus.

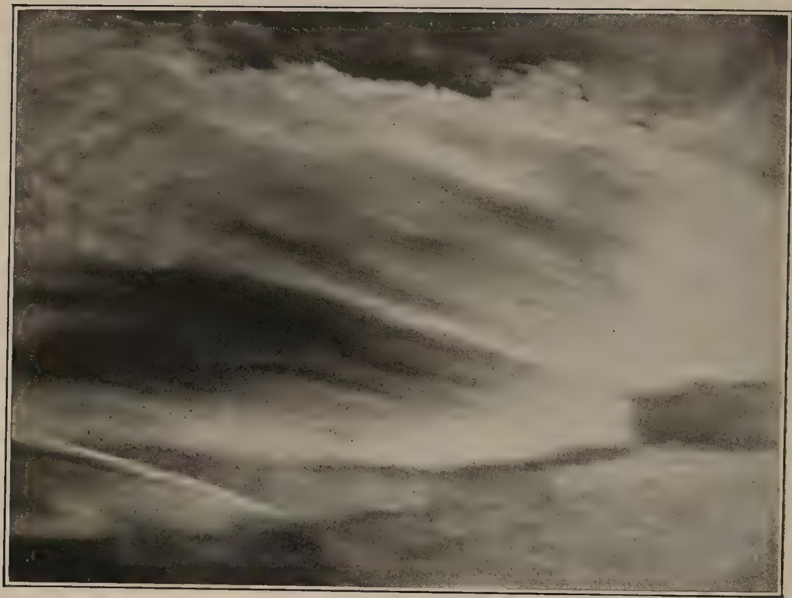
PLATE 19.

19A. *Alto-cumulus.* The most typical form of alto-cumulus, all the characteristics of that cloud-type as described in the International classification being present in this picture. The two wave-systems crossing each other ("double undulation") are very clearly shown, and the solid character of the cloudlets is well brought out by the slight shadows upon them.

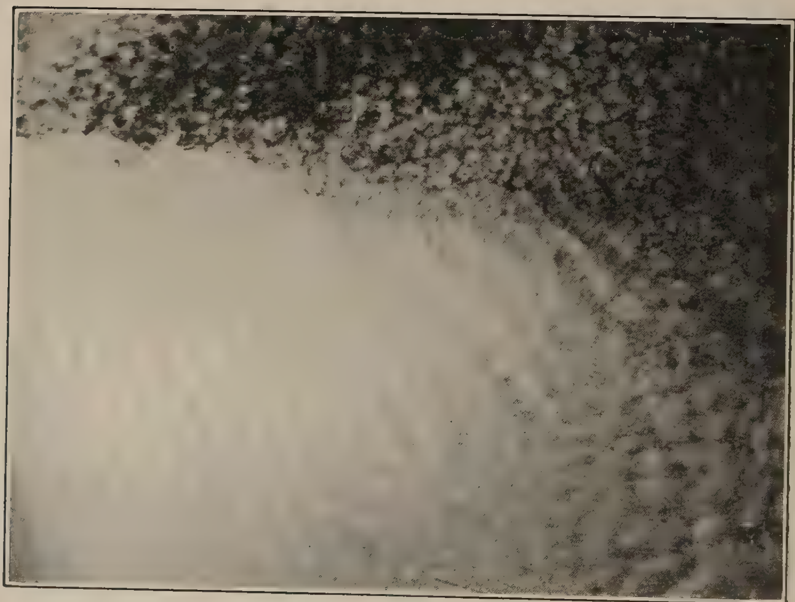
19B. *Alto-cumulus.* The edge of a very compact sheet of alto-cumulus wherein the separate cloudlets are compressed and fused into each other. The lack of areas of blue sky between the cloudlets is compensated for by the light of the sun (which is directly behind the cloud) throwing into strong light and shade the differing thickness of the cloud-sheet, and thereby revealing the globular form of the component cloudlets. At the right-hand edge of the cloud-sheet there may be seen, against the blue sky, a large number of very small incipient cloudlets; these formed a fringe along the whole length of the cloud-layer.

A

B



A



B

PLATE 20.

20A. *Cirro-cumulus Lenticularis.* Three lenticular-shaped banks of cirro-cumulus clouds that have become so much fused as to lose entirely their "cumulus" character. This is a very common occurrence with cloud of this type, and it is often only at the leeward edge of the cloud-bank that the real character of the cloudlets becomes evident. Only very slight traces of it can be seen in this picture, but in the example below it is clearly shown.

20B. *Cirro-cumulus Lenticularis.* A portion of a cloud-bank of this type, wherein there is shown a very beautifully rippled under-surface, greatly resembling the surface of rippled water. The cloudlets are passing outwards from the cloud-bank and moving towards the right, where it will be seen that their cirro-cumulus form is perfectly normal.

PLATE 21.

21A. *Cirro-cumulus Lenticularis.* Here cirro-cumulus cloudlets in long waves are massing together into a complicated system of lenticular banks. The cloudlets were moving with a very high velocity, but the cloud-banks remained practically stationary for many hours, though their details and sizes were rapidly varying. The great density of some of the banks is well shown in the lower part of the picture.

21B. *Cirro-cumulus Lenticularis.* A very large compound lenticular cloud-bank with several small detached single clouds. This picture is probably the most beautiful cloud photograph taken so far by the writer, and shows a wonderful sunset effect upon the rippled under-surface of the cloud-bank. The colours were very beautiful, the sky itself varied from deep ultramarine at the top to emerald green near the horizon, and the small dark masses of strato-cumulus cloud were cold grey-purple with flame-coloured edges. The large cloud-bank was of a deep ochre-yellow tint, while its edges and the sunlit ripples on its under-surface were outlined in blazing gold. The system of double undulation shown by the ripples is a specially remarkable one.

A

B

A

B

PLATE 22.

22A. *Alto-cumulus Lenticularis.* Lenticular cloud-banks at the alto-cumulus level. Here again the individual cloudlet character is suppressed, but may be seen in the bright portions of the two nearer banks of cloud. In this instance, the banks overhead were composed of clearly defined alto-cumulus.

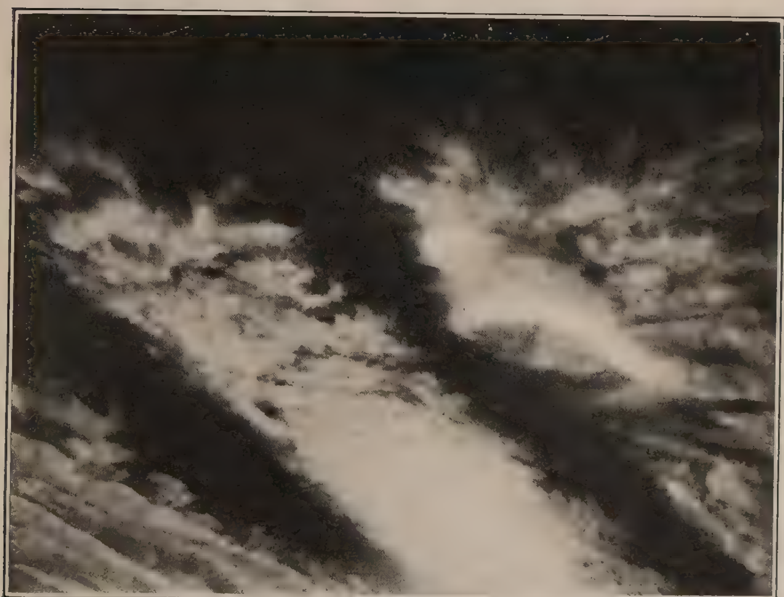
22B. *Alto-cumulus Lenticularis.* A series of these cloud-banks well depicted at sunset. The relatively great density of the central parts is plainly to be seen, as also is the comparative thinness at their edges. In the upper part of the photograph, the individual cloudlets are seen passing out of one bank and entering another. The proper method of distinguishing between cirro-cumulus and alto-cumulus when they are massed into banks of this type is to examine the individual cloudlets that are nearest to the observer, for the banks themselves give very little indication of any difference when they are at all dense or very distant.

PLATE 23.

23A. *False Cirrus.* Heavy masses of the so-called *false* cirrus surmounting some small cumulo-nimbus shower-clouds from which rain may be seen falling. The false cirrus plumes will be seen to be less clearly defined than those of the ordinary cirrus, though resembling them in their wispy arrangement. They are also heavier and denser in texture than the true cirrus plumes.

23B. *False Cirrus becoming Alto-cumulus.* The cloud shown in this picture had shown the ordinary cirrus character only a few minutes before this photograph was taken. Here the last fibres of the false cirrus will be seen on the extreme right in process of transformation into the characteristic form of alto-cumulus. In the central band, and in that at the lower left corner, the transformation is progressively further developed, being complete in the last-mentioned-band.

A



B

A

B

PLATE 24.

24A. *Alto-cumulus Castellatus.* The "turret-cloud," the form of alto-cumulus that is so often a precursor of thunderstorms. Its resemblance to the ordinary cumulo-nimbus of lower levels is shown clearly by its considerably developed vertical structure and by the rounded protuberant upper surfaces of the cloudlets.

24B. *Alto-stratus.* The characteristic grey pall of intermediate cloud through which the sun is shining weakly. Some loose "scud" in dark ragged masses—the forerunners of the coming nimbus—may be seen moving up below the alto-stratus. This is an example wherein the alto-stratus is quite structureless.

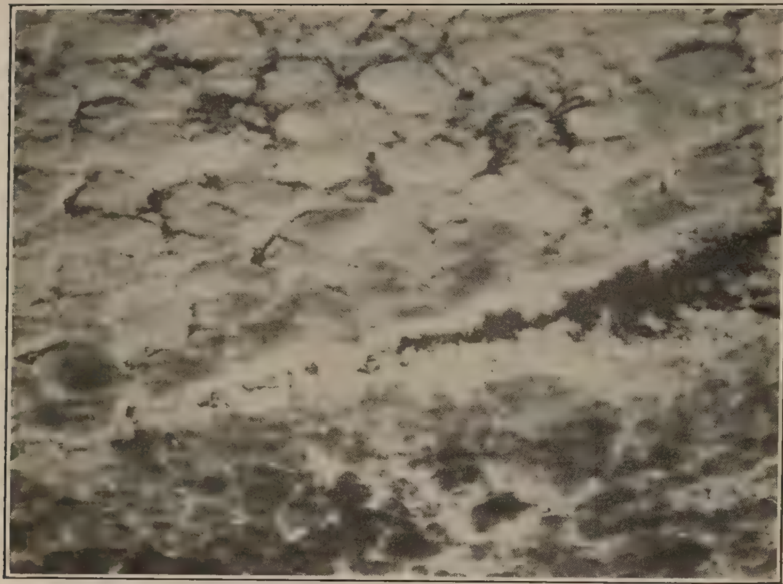
PLATE 25.

25A. *Strato-cumulus.* The typical form of this cloud. The masses are heavily shaded, and tend to fuse into each other within the sheet, while at the edges of the sheet they appear separated, so that the blue of the sky can be seen between them.

25B. *Strato-cumulus.* A still heavier form than that above mentioned. This is the type of cloud-sheet that may cover the whole sky for days on end, especially during the winter months. The cloud is dark grey with bright yellowish-white interstices where the sun is shining through the thinner parts of the sheet. The edges of the clouds are fused together; little or no blue sky can be seen between them.

A

B



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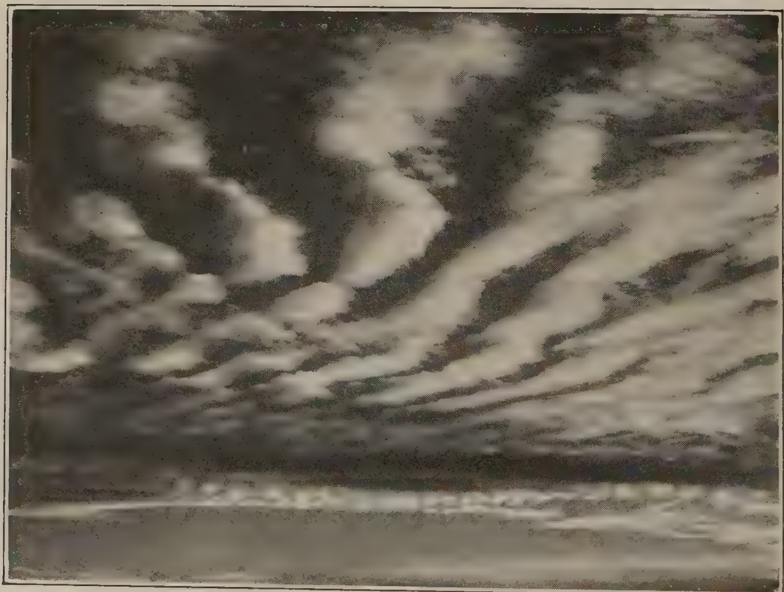


B

PLATE 26.

26A. *Strato-cumulus.* A high variety of strato-cumulus, almost as small and fine as alto-cumulus, but this condition existed only at the edge of an extensive sheet of cloud which was otherwise indubitably strato-cumulus. An edging of smaller cloudlets is a usual feature in cloud-sheets of this type. The cloudlets in this picture are thin and flat, almost like small plates or slabs.

26B. *Strato-cumulus.* Part of a long band composed of a series of very sinuous transverse waves. The dark horizontal band is a belt of thin stratiform cloud formed just below the strato-cumulus waves. It is from such films or thin sheets of stratus that occasional transient showers fall.

PLATE 27.

27A. *Strato-cumulus.* Connected strato-cumulus cloudlets of somewhat lenticular form exhibiting a wave-form arrangement. It is worthy of note that the lower band, the one composed of four cloud-masses, was not in one connected whole when first seen. A photograph taken a few minutes previously showed the second cloud-mass from the left to be connected with the now isolated cloud just below it, but separation from this latter cloud took place simultaneously with the connecting-up of the second and third clouds in the line. A wave-system that had been visible an hour earlier was thus re-established.

27B. *Strato-cumulus.* Four very straight and well-defined bands of strato-cumulus of a very heavy type. The bands were moving towards the observer at right angles to their length, and were approximately a mile in breadth, the intervening spaces of sky being also about a mile broad.

A

B

A

B

PLATE 28.

28A. *Cumulus.* Small cumulus clouds at an early stage in their development. They are photographed with the sun behind the largest cloud in order to show the characteristic bright edge surrounding the dark cloud, the appearance which is popularly known as the "silver lining".

28B. *Cumulus.* A very typical cumulus cloud of rather large dimensions and pronounced shape. The dome-shaped or pyramidal structure is very evident, the numerous protuberances which indicate the rising currents may be seen, while the flatness of the dark base, which marks the level of condensation, is also well shown. Cumulus clouds of large dimensions, like this one, are those that very frequently continue growing till they become cumulo-nimbus.

PLATE 29.

29A. *Cumulus.* A rather unusual arrangement where the cumulus clouds are grouped into long parallel lines very much like the parallel waves seen in the higher clouds. The cumulus clouds, however, were moving in the same direction as that in which the lines were lying, whereas the waves in the higher clouds usually travel at right angles or at some other considerable inclination to their length.

29B. *Cumulus* (with *Alto-cumulus* above). A line of connected cumulus clouds near the coast-line. They appear dark chiefly because the sun is behind them a little to the right of the picture, and is also partly obscured by the layer of fused alto-cumulus above. At Aberdeen it is fairly common for cumulus clouds to form in line along the coast on winter mornings, when a slight cold westerly breeze from the land may undercut and elevate the warmer sea air that may be moving from south or north.

A

B

A

B

PLATE 30

30A. *Cumulus* (and *Fracto-cumulus*). Small cumulus clouds mixed with a considerable amount of the broken variety known as fracto-cumulus. The latter form seems to be accompanied by much turbulence and is found often in squally weather.

30B. *Cumulus* (becoming *Strato-cumulus*). In this picture cumulus clouds are shown in the process of flattening out and assuming the character of strato-cumulus. Air conditions are then becoming more stable and vertical currents are dying out; the type is therefore found more frequently towards evening.

PLATE 31.

31A. *Cumulo-nimbus.* A large thunder-cloud with a very flat base from which rain is falling in the far distance. In the near front of the cloud-mass the moisture in the rising currents is condensing and spreading out into a large "anvil" which is fringed with false cirrus threads. Far in the rear there may be seen more false cirrus from other parts of the cloud-mass, which latter seems to be formed by the union of several cumulo-nimbus clouds.

31B. *Cumulo-nimbus.* The right front portion of a large thunder-cloud which shows no "anvil". The cloud is moving away from the observer and in its front the white protuberant masses of condensation are rising, while in the rear they are falling in rain, and appear grey in colour. The basal part of the cloud is formed by a sheet of intensely dark cloud of nimbus type.

A

B

A

B

PLATE 32.

32A. *Cumulo-nimbus.* An advancing hail-shower cloud that is practically all "anvil". Some small growing cumulus may be seen in front. The finely-formed anvil is topped and surrounded by false-cirrus filaments. The passage of the cloud overhead was accompanied by a heavy squall with hail.

32B. *Cumulo-nimbus.* Another hail-squall cloud. It is moving from left to right, and showers are falling from it over the sea. As the cloud moves forward the rising moist air forms in front of it a line of growing cumulus which lies round the front of the main cloud like a collar.

PLATE 33.

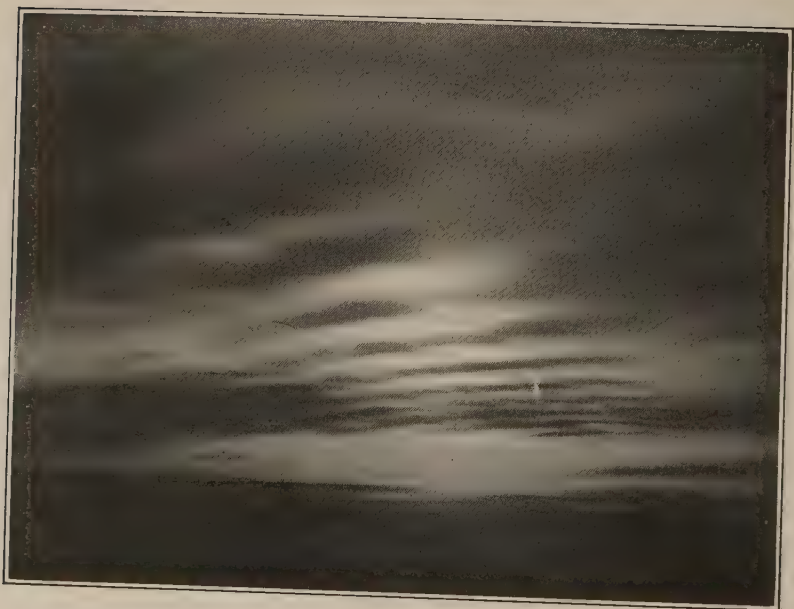
33A. *Cumulo-nimbus.* This is an example showing rapidly-growing vertical columns of cloud that are uniting to form a huge thunder-cloud, of which this photograph includes less than one-fourth. A quantity of loose fracto-cumulus is floating round the main mass.

33B. *Mammato-cumulus.* The appearance often seen under the base in the rear part of thunder-clouds, and sometimes also seen widespread on the under surface of a cloud-sheet which resembles closed strato-cumulus. In the latter case it is quite possible that the upper surface of the cloud, if it could be seen, would be of the cumuliform type. Rain is either falling at the time this formation is visible or it follows soon after. In this picture the cloud substance is being whirled down and up again by the turbulence of the air-currents. It is a dangerous cloud for aviators.

A

B

A



B

PLATE 34.

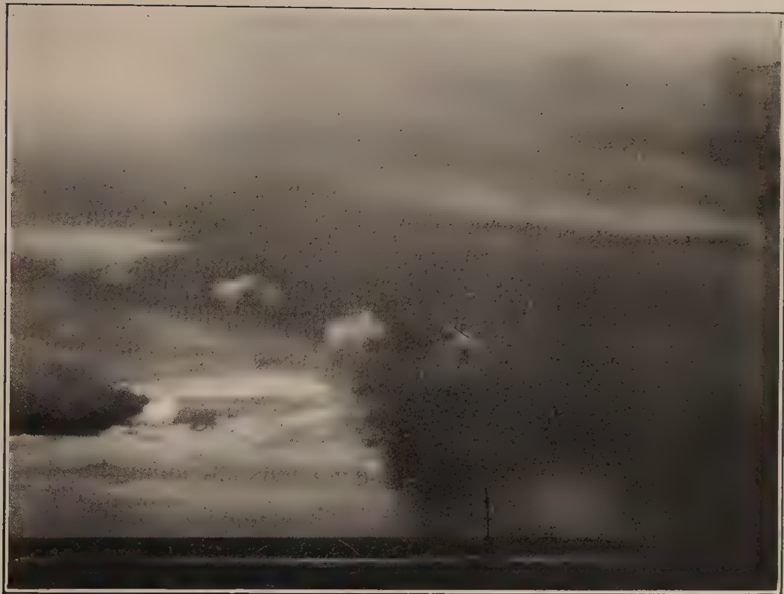
34A. *Stratus.* This is the really typical form of stratus, a grey pall of cloud without any detail, and rendered visible only by the fact that the summit of the distant hill is immersed in the cloud, which is trailing along its flanks in the ragged masses called *fracto-stratus.*

34B. *Stratus.* An evening sky with a sheet of thin lifted fog passing overhead from seaward in a series of beautiful waves, which, however, are so thin as to permit the sun's disc to be seen through them quite clearly. The cloud greatly resembles strato-cumulus in its arrangement, but its thinness and the obviously small altitude it showed proved it to be stratus, and in a very short time the cloud-layer had become quite uniform normal stratus.

PLATE 35.

35A. *Nimbus.* Actually a shower falling from the nimbus-base of a large cumulo-nimbus cloud. It is impossible to photograph the typical nimbus cloud because the rain, when general, is not visible to the camera. It is only when an isolated shower shows dark against the lighter sky beyond that the rain can be shown.

35B. *Nimbus and a Rainbow.* A screen of rain is falling in the middle distance, and a primary rainbow, with a faint outer secondary bow, have become visible. The lighter space within the primary bow is plainly shown, and near the crest of the arch several supernumerary bands are seen.



A

B

A

B

PLATE 36.

36A. *Line-Squall Cloud.* The first stage, showing the beginning of the formation of the long line of cloud (see p. 63 for description). This and the three following pictures are from pastel sketches made by the writer from personal observation.

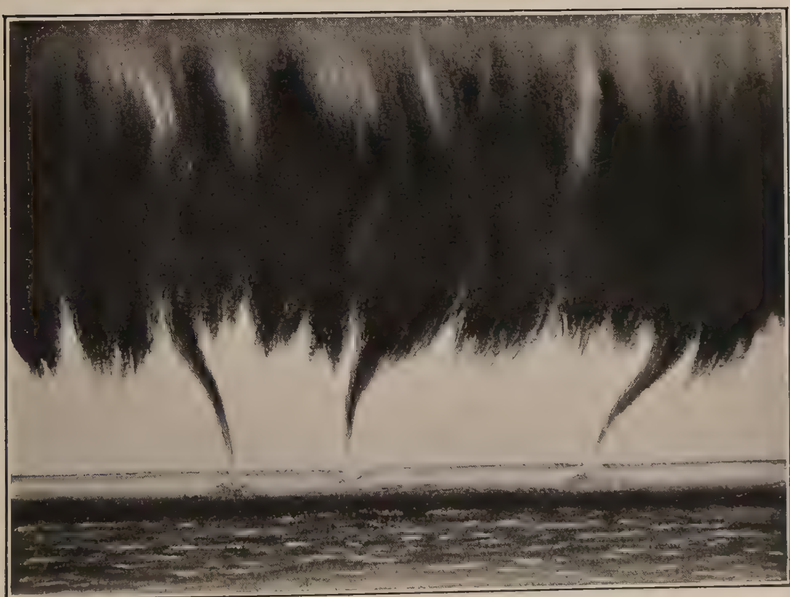
36B. *Line-Squall Cloud.* The second stage, where the long line of cumulus has become complete; the sheet of dark nimbus may be seen following the squall front. The nimbus sheet was higher than the line of cumulus, and followed it with a slight interval between them.

PLATE 37.

37A. *Line-Squall Cloud.* The third stage—the line of cumulus after it had moved out over the sea. The cloud was losing its cumuliform character and beginning to show some vertical arrangement, while small wisps of condensation were moving up and down below the cloud front.

37B. *Line-Squall Cloud.* The fourth stage, showing the cloud front after the formation of the three waterspouts. The cloud was a whirling turbulent mass with very ragged edges which were drawn out into thin filaments. Further observation was prevented by the heavy shower which hid the cloud front from view.

A



B

A

B

PLATE 38.

38A. *Cumulo-nimbus.* A view from above of a massive heap of cloud which reached from 1,000 to 10,000 feet above the ground, that is to say, it was nearly two miles in depth. The tops of the rising air columns are seen remarkably well in this view.

(Aeroplane photograph by Capt. C. K. M. Douglas, R.A.F.)

38B. *Strato-cumulus.* A close view of the upper surface of a turbulent sheet of strato-cumulus. The top of the sheet was 5,000 feet high, and an inversion of 10° F. occurred above it.

(Aeroplane photograph by Capt. C. K. M. Douglas, R.A.F.)

PLATE 39.

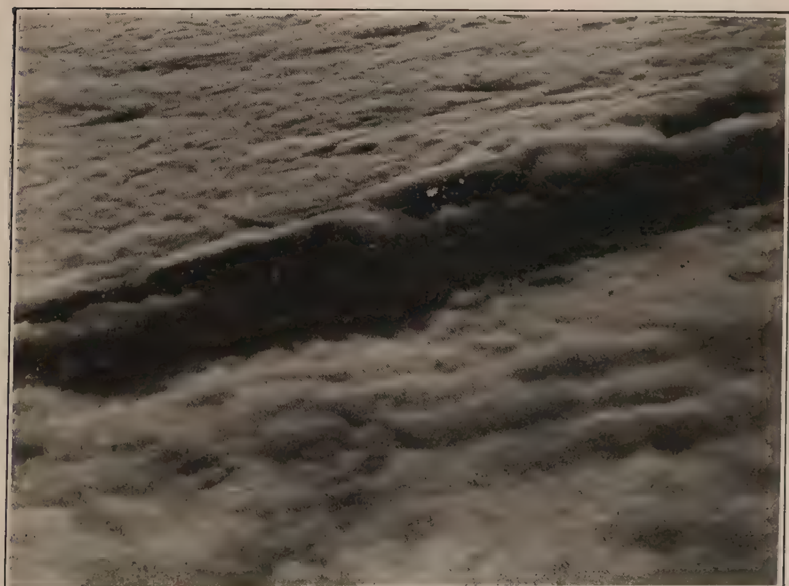
39A. *Strato-cumulus.* The top of a cloud-sheet whose height was 9,700 feet, considerably above the average height of that particular type of cloud. The cloud billows are very clearly shown, one system of waves or folds crossing the other at an angle of about 30°. There was an inversion of 3° F. above this layer.

(Aeroplane photograph by Capt. C. K. M. Douglas, R.A.F.)

39B. *Strato-cumulus.* Upper surface of a normal strato-cumulus cloud-layer, across which there runs a "cliff-front" of cloud. The height of the surface in the foreground was 3,800 feet, that of the surface beyond the "cliff-front" was 4,500 feet, there was thus a sheer rise of 700 feet along the "cliff" line.

(Aeroplane photograph by Capt. C. K. M. Douglas, R.A.F.)

A



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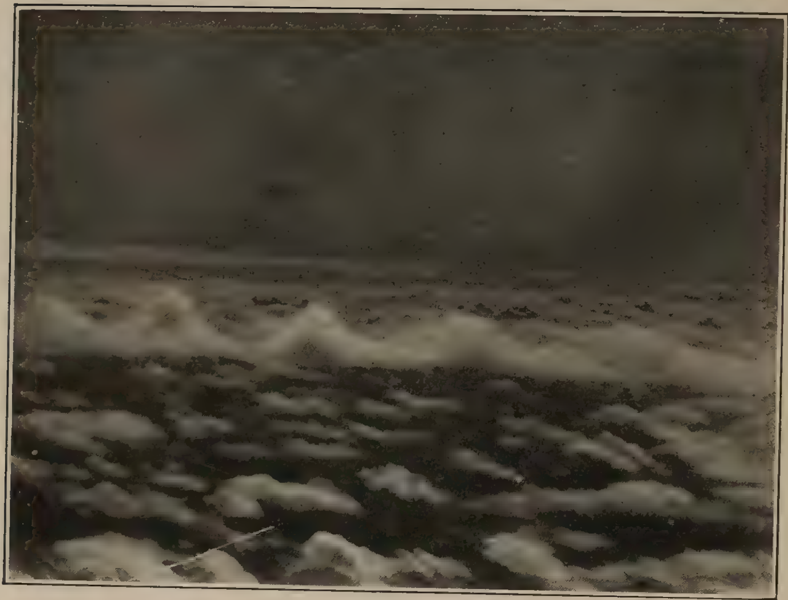

A

B

PLATE 40.

40A. A long narrow strip of cloud rippled into waves which was formed in a damp layer at 4,000 feet. Below it there are floating a large number of small cumulus which had formed at 1,000 to 1,500 feet from a sheet of stratus.

(Aeroplane photograph by Capt. C. K. M. Douglas, R.A.F.)

40B. *Cumulus.* A view taken above a layer of cumulus clouds, showing three cloud summits which had become detached from three pillars of condensation that towered upwards from the sheet below. The intervening parts of the cloud-pillars had evaporated again.

(Aeroplane photograph by Capt. C. K. M. Douglas, R.A.F.)

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